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# Towards a generalized team task complexity model

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# TOWARDS A GENERALIZED TEAM TASK COMPLEXITY MODEL

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## ABSTRACT

The objective of this research was to develop and validate a generalized team task-complexity model and framework by drawing on the literature from various team and task factors grouped into three task-dimensions, which compose task-complexity space and how these affect the task-performance. A number of task typologies have been presented in the teams' literature to better define and understand the critical role of the tasks and the associated team processes. In addition, most of the research work has defined team measures as highly abstract concepts not capable of providing the quantitative comparison of team performances from various domains.

This research proposed a model of task-complexity based on different task-characteristics including task-scope, task-coordination and task-uncertainty that provide the capability to quantify different attributes that impact team performance. A multiple linear regression analysis was used to validate the contribution of each task-complexity dimension towards complexity and performance. Analysis of variance was also used to account variance in measurement scales and not to force linear relationship.

The results indicate a significant three-way interaction of task-scope, task-coordination and task-uncertainty. Since three-way interaction was significant, all the three task-complexity dimensions were significant and not equally contributing towards team task-performance. Two-way interaction of task-scope and task-coordination was significant when task-uncertainty was negligible. Thus both were not equally contributing towards team task-performance. From effect tests, task-coordination and task-uncertainty were found to be highly significant with relation to task-performance. Though task-scope was not significant, further analysis reveals that it had

significant impact on task-performance at its highest level and when task-uncertainty was negligible. Thus explains its inclusion in the three-way interaction.

Workload, a subjective team performance measure in team literature, was used for model cross-validation. Results found a significant negative correlation between perceived task-workload and task-performance, thereby validating the model from workload perspective. This study summarizes the different task-characteristics affecting the team task-performance. This study has practical implications in the design and evaluation of collaborative tools and team training. Further research would develop a synthetic collaborative system that would emulate certain complex work environments and enable the collection of team performance data for assessing hypotheses about collaboration.

# CHAPTER 1

# INTRODUCTION

Today's organizations are increasingly using teams to streamline processes, enhance participation, and improve quality (Cohen and Bailey, 1997). The use of teams in organizations has expanded dramatically to solve complex problems and to get a competitive edge over competitors. Hence, teams are becoming the primary building block of most organizations (Brooks, 1994; McGrath, 1997). A recent study by Gordon (1992) found that 82% of American companies with strength of 100 or more employees utilize some form of teams. Irrespective of private or public sector organization, the reliance on teams and work groups is present. Teams are found in diverse fields such as education, science, engineering and technology, and the military.

With 'teams' comes the term 'task' that they need to perform in order to solve organizational problems. That's why some early researchers treated teams as vehicles for performing tasks (Arrow, McGrath, and Berdahl, 2000). Because task performance was central to these early researchers, a part of their research dealt with the effects of different types of tasks on performance of the teams (e.g., Kent and McGrath, 1969; Steiner, 1972; McGrath, 1984). Thus the tasks which experimental teams are asked to undertake has proven to be one of the important moderators of team behavior and effectiveness (McGrath, 1984). Since teams engage in many different collective activities, a number of task typologies and descriptions have been presented in the team and related literature in an effort to better define and understand the critical role of the tasks and the associated team processes.

Roby and Lanzetta (1958) proposed one of the first useful team-task classification systems in which tasks are classified based on an analysis and definition of the properties (objective and modal properties) of the task. They also suggested that classification should involve a description of the properties of the relationships between critical task events. This is a very important task typology as it represents one of the first systems for quantifying tasks based on both objective task characteristics and behavioral requirements. Task typologies by Hackman (1969), McGrath (1984), and Wood (1986) were built based on this system. But it is Wood (1986) that suggested that the construct of the task complexity might represent a more useful means for differentiating tasks. However as defined by Wood, the task complexity construct applies to individuals rather than groups (Wood, 1986; p.66). But later researchers concluded that since the model of the task complexity is built on the task as behavior requirements and task qua frameworks (frameworks which are independent of the task performers), that the task complexity construct could be applied to group tasks as well. Thus the nature of the task complexity dimension has long been a topic of consideration in teams and small groups' research.

## 1.1 Rational and Objectives

The predominance of team decision-making and performance assessment literature has defined team measures as highly abstract concepts. Terms such as team leadership, competence, innovation, and empowerment are replete in team literature (Brannick, Salas, and Prince 1997, Smith-Jentsch, Johnson, and Payne 1998). While these terms are intuitively appealing (e.g. successful teams are empowered), they are often without specified mathematical meanings and, therefore, without quantifiable relationships to other team constructs. Characterizations that most successful teams are well-led, innovative, competent, and empowered are helpful criteria for expert practitioners who have their own sense of what these terms mean. However, they are of less utility when informing the design of training systems for future team technologies.

Most complex decisions involve many data, human, and technological sources collaborating to support decision makers. However when the responsibility for task accomplishment moves from the province of one person to a multitude of natural and artificial intelligences, the system changes quantitatively and qualitatively. Quantitatively, the system is more complex and dynamic. This complexity increases further as the constituent intelligences are separated in time. Qualitatively, the system exhibits properties that were not evident when a lone individual is working on a set of tasks.

Thus the tools and methodologies that have been developed to understand the work of the sole individual do not necessarily accommodate the interaction of multiple members. Much work has been done to attempt to understand the team environment in the form of cognitive engineering, computer cooperative supported work, and groupware. Much of the work in this area focuses on teams that create a common artifact where debate and negotiation are often not constrained by time.

This research focuses on the team task-complexity space and how any team task can be represented in this team task-complexity space, of three dimensions, by objectively assessing team performance in any task environment. Further this research develops a generalized team task-complexity model and dimensions which is built on the team task-complexity dimensions proposed by Harvey (1997) and Harvey (2001). Considering the practical difficulty of experimentally testing many tem-tasks from different domains, a thorough validation of these task-dimensions is done my experimentally testing a number of team-tasks designed within a particular selected domain of command and control. Objectively quantifying task-complexity dimensions pave the way for comparing the different team tasks of different complexity levels in different environments.

# CHAPTER 2

# LITERATURE REVIEW

Since the teams and teamwork are becoming more important and common, the answers to some basic questions concerning teams also become more important. Some of the basic questions about teams include: How do teams work? What factors affect team performance? How does one assess team performance? In order to answer these questions and to know more about what have researchers done related to teams, let us look into the literature on teams and small groups. The lay out of team literature section consists of an overview of team and its definition, typology of teams, team theories and models.

## 2.1. What Is Team?

The words “team” and “group” are both equally prevalent in team literature. But most of the popular management literature uses the term “team”(e.g. team effectiveness, marketing teams) where as the academic literature uses the word “group”(e.g. group cohesion, group dynamics). According to some researchers groups vary in their degree of “groupness” (how much the team/group members dependent on each other), with some groups being more interdependent and integrated than others. According to Brannick and Prince (1997) teams can be distinguished from small groups as teams have unique requirements for coordination and task interdependency. Some authors use ‘team’ for groups that have a high degree of “groupness” (Katzenbach and Smith, 1993). In other words, groups become teams when they develop a sense of shared commitment and strive for synergy among the members (Guzzo and Dickson, 1996). Though there might be some differences between the terms ‘team’ and ‘group’ expressed by some researchers throughout this document, the terms ‘team’ and ‘group’ are used interchangeably for convenience. Before going into the details about what researchers have done related to teams, let us define the term team. Multiple definitions exist for the term 'team'.

### 2.1.1 Team Definition

Several definitions of team exist within the team and small group literature including,

1. Teams consist of two or more individuals, who have specific role assignments, perform specific tasks and who must interact or coordinate to achieve a common goal or outcome. (Baker and Salas, 1997)
2. Teams consist of two or more individuals, who make decisions (Orasanu and Salas, 1993)
3. Teams consist of two or more individuals, who have specialized knowledge and skills (Cannon-Bowers et. Al., 1995).
4. Team is a bounded system composed of a set of interdependent individuals organized to perform specific tasks that affect others (Guzzo and Dickson, 1996).
5. "A team is a collection of individuals who are interdependent in their tasks, who share responsibility for outcomes, who see themselves and who are seen by others as an intact social entity embedded in one or more larger social systems (for example, business unit or the corporation), and who manage their relationships across organizational boundaries" (Cohen and Bailey, 1997).

    By this definition, team members from the same department who work on separate projects is not a team. The above definition was derived from the work of Hackman (1987) and Sundstrom, De Meuse, and Futrell (1990).

6. A team is a complex, adaptive, dynamic, coordinated, and bounded set of patterned relations among team members, tasks, and tools. (Arrow, McGrath, and Berdahl, 2000).

Arrow, McGrath, and Berdahl (2000) definition of team is a very comprehensive one. Their definition is based on the synthesis of a vast literature on teams and small groups. They included complex, adaptive and dynamic nature of teams along with coordination and relationships among team members to define teams. But most important thing is the notion of considering relationships among team members, tasks and tools into the definition. Thereby stating teams as not mere group of people who work together on a common objective and share the work responsibilities but also the tools they utilize to perform and relations among team members, tasks and tools.

### 2.2 Team Theories and Models

In general there are three important team theories and models in the team literature. They are input-process-output model (McGrath, 1984; Hackman, 1987), maturation models (e.g. Team Evolution And Maturation (TEAM) model (Morgan et al., 1986), Forming-Storming-Norming-Performing Model (Tuckman, 1965)) and Adaptability model (Entin and Serfaty, 1999).

#### 2.2.1 Input-Process-Output Model

A good amount of team theory and research is based on the classic systems theory of input-process-output (Ilgen, 1999). However it is McGrath (1984) and Hackman (1987) who described traditional small groups research of classic systems theory terms with inputs, processes, and outputs. Inputs usually include the task characteristics, some elements of context and people who composed the teams. Processes include interactions among the team members, communication, coordination and interpersonal influence mechanisms like leadership. Outputs include task-focused things such as team performance outcomes such as performance quality and number of errors and socio-emotional outcomes such as member satisfaction and group cohesiveness. Traditional approaches have tended to focus more on the development of psychological process theories (e.g. Steiner's (1972) Model of Group Process and Cooper's (1975) book on theories of group processes). Teams tasks, contexts, and composition (on input side) often were of interest only as boundary conditions there by restricting behaviors and contexts over which process theories generalized. In organizations, inputs like task characteristics and outputs like task performance, are more important and critical team factors (Ilgen, 1999). As organizations use more teamwork oriented approaches the importance of teams and team behaviors increases. Thus more research is focused on the identification and determination of input factors like task-context and behavioral factors that contribute to effective teamwork, and output factors like team performance. This change in orientation leads to the development of normative models. Since most of all the earlier research on small groups is descriptive, Hackman (1987) identified the need of normative models. Normative models in contrast to descriptive ones (input-process-output model) usually start with a purpose to develop ways to improve teams so that behavior on them will meet some objective (Ilgen, 1999). Hackman's (1987) work on the design of work teams is an example of a normative model as he is explicit in the goal to develop a model based on the scientific data available that will increase the probability that teams with characteristics outlined in the model will perform better.

### 2.2.2 Pinsonneault and Kraemer's Model

Pinsonneault and Kraemer (1989) came up with another framework/model for analysis from systematic review of research in organization behavior and group psychology. Pinsonneault and Kraemer (1989) conceptualized and framed their group model more or like in the similar lines of traditional input-process-output model. But their prime concern is the technological support and group outcomes. Pinsonneault and Kraemer's model consists of four broad sets of factors. They are

1. Contextual Variables: Contextual variables refer to factors in the immediate environment of the group rather than in the broader organizational environment. Five contextual variables appear to be important in the behavioral research on groups: personal factors, situational factors, group structure, technological support, and task characteristics.
2. Group Process: Group process variables refer to characteristics of the group's interaction and attempts to capture the dynamics of that interaction. Group process includes decisional, communication, interpersonal characteristics, and structure imposed by Group Decision Support Systems (GDSS) and Group Communication Support Systems (GCSS).
3. Task-Related Outcomes: Task-related outcomes include characteristics of the decision, implementation of the decision and attitude of group members. Each of these variables further affected by technological support.
4. Group-Related Outcomes: Group-related outcomes include satisfaction of the group members with regard to the process and their willingness to work in groups in future. Both task-related and group-related outcomes are further interrelated.

The prime goal of this model was to address the technological support to groups and its help in reducing the errors in decision processes as well as reducing the communication barriers between members of group (Pinsonneault and Kraemer, 1989). This model suggested that Group Decision Support Systems (GDSS) increase the task-oriented communication and clarification efforts; increase the degree of participation and decrease the domination by few team members; and increase the consensus among members of the group. These impacts further increase the quality of decisions, which in turn increase the confidence and satisfaction of group members towards the decision. Similarly the model showed that Group Communication Support Systems (GCSS) increase the total effort put in by the group member and also increase the participation of group members thereby increasing the quality of decisions. However results indicated surprisingly that GCSS decreases the overall cooperation thereby resulting a decrease in the confidence of group members taking decisions. This model further paved way for the importance and need of technology introduction to assist teams.

### 2.2.3 Maturity Models

In addition to the input-process-output models, maturity models have found an important place in team literature. Some examples of the maturation models are Forming-Storming-Norming-Performing (FSNP) Model (Tuckman, 1965), Team Evolution And Maturation (TEAM) model (Morgan et al., 1986).

#### 2.2.3.1 Forming-Storming-Norming-Performing Model

Tuckman (1965) proposed a team model that shows the four stages that teams go through: from Forming to Storming to Norming to Performing.

In the Forming stage, team members are introduced. They state why they were chosen or volunteered for the team and what they hope to accomplish within the team. Members cautiously explore the boundaries of acceptable group behavior. This is a stage of transition from individual to member status, and of testing the leader's guidance both formally and informally. Because there is so much going on to distract members' attention in the beginning, the team accomplishes little, if anything, that concerns its project goals. Which is considered perfectly normal.

The Storming phase is called the team's transition from the "As-Is" to the "To-Be". All members have their own ideas as to how the process should look, and personal agendas are rampant. Storming is probably the most difficult stage for the team. They begin to realize the tasks that are ahead are different and more difficult than they imagined. Impatient about the lack of progress, members argue about just what actions the team should take. They try to rely solely on their personal and professional experience, and resist collaborating with most of the other team members.

The Norming phase is when the team reaches a consensus on the “To-Be” process. Everyone wants to share the newly found focus. Enthusiasm is high, and the team is tempted to go beyond the original scope of the process. During this stage, members reconcile competing loyalties and responsibilities. They accept the team, team ground rules, their roles in the team, and the individuality of fellow members. Emotional conflict is reduced as previously competitive relationships become more cooperative.

The team has now settled its relationships and expectations. They can begin performing by diagnosing, solving problems, and choosing and implementing changes. At last team members have discovered and accepted each other’s strengths and weakness, and learned what their roles are. The team is now an effective, cohesive unit. You can tell when your team has reached this stage because you start getting a lot of work done according to Tuckman (1965).

#### 2.2.3.2 Team Evolution And Maturation (TEAM) Model

Traditional descriptive team models do not deal with the temporal aspects of team performance or the processes involved in the development of teams as a result of time, experience, or training (Morgan, Salas, and Glickman, 1994). As a result team performance was not addressed in a systematic way. Later on team-performance gained more attention as an important aspect. Thus a number of approaches to team performance have evolved. Four are mentioned here as illustrations of different ways to address team performance. Morgan and his colleagues (Baker and Salas, 1992; Cannon-Bowers et al., 1995; McIntyre and Salas, 1995; and Morgan et al., 1986) followed the classic criterion development model to construct the Team Evolution And Maturation (TEAM) measure of team performance.

Morgan et al. (1986) postulated that there are two distinguishable tracks that co-develop over the maturation period of a team: a taskwork track and a teamwork track. Taskwork consists of behaviors that are performed by individual team members and are critical to the execution of individual team member function. Teamwork consists of behaviors that are related to team member interactions and are necessary to establish coordination among individual team members to achieve team goals. In general, critical teamwork behaviors were organized around seven behavioral dimensions: giving suggestions or criticisms, cooperation, communication, team spirit and morale, adaptability, coordination, and acceptance of suggestions or criticism (Salas et al. 1995).

Later the TEAM research took a longitudinal approach to meet its goals providing the opportunity to look into teams' development over a period of time. That laid the foundation further by looking into real operational teams working in natural contexts like high workloads, time pressure and to deal with complex situations (McIntyre and Salas, 1995). This kind of methodology helps in examining behaviors that distinguish effective teams from less effective teams and is used extensively by Navy researchers. But Morgan and his colleagues' (1986) themselves depicted and discussed four sub-dimensions of teamwork that were needed for effective teams (performance monitoring, feedback, closed-loop communications, and backing-up behaviors) and paved the way for methodology of distinguishing effective teams from less effective teams.

### 2.2.4 Team Adaptation Model

Entin and Serfaty (1999) proposed a theoretical framework for team adaptation, which also closely resembles the traditional input-process-output model. In this adaptation model, inputs are operational conditions, individual/team characteristics, and team structure. These inputs are connected to stress processes, which in turn connected to team processes having taskwork and teamwork tracks. The taskwork track and teamwork track form a feedback loop by connecting back to stress processes by means of decision-making adaptation and coordination adaptation respectively. Teamwork track also makes a feedback loop with team structure, part of input, by means of structural reconfiguration. Finally the team processes are connected to performance (output). Here the adaptation strategies used by teams to manage the stress processes and are represented in the form of feedback loops.

Effective teams are able to 'push' information and action to team members before it is needed as opposed to 'pulling' information and actions from each other under stress (high-workload conditions) (Entin and Serfaty, 1999). Underlying the notion of anticipation is the idea of a shared mental model of the team and the task. That is, because members understand the team task, and each other's task roles and functions, effective teams are able to anticipate what information and action other team members need. The dual concepts of shared mental models and adaptive coordination are a productive approach for understanding and developing effective teamwork. There are many methods by which team members can acquire anticipation skills and shared mental models. These include cross training on others' jobs (Cannon-Bowers et al., 1998), and training feedback on teamwork behaviors (Stout, Salas and Fowlkes, 1997).

### 2.3 Typology of Teams

According to Cohen and Bailey (1997) four types of teams can be identified in organizations today: (1) work teams; (2) parallel teams; (3) project teams; and (4) management teams. Other researchers such as Sundstrom, De Meuse, and Futrell (1990) used integration and differentiation as the taxonomy to differentiate the four types of groups. They define teams as (1) advice and involvement groups; (2) production and service teams; (3) project and development teams; and (4) action and negotiation teams. Though Cohen and Bailey (1997) and Sunderstrom, De Meuse, and Futrell (1990) offer different typologies in identifying different teams, their categories overlap with each other. Though the names kept by researchers are different, Cohen and Bailey argue that their categories overlap with others. For example work teams correspond to production and service teams, parallel teams correspond to advice and involvement teams and project teams correspond to project and development teams. Similarly management teams correspond to action and negotiation teams. Thus while the names may defer their definitions are very similar. Following is a brief explanation to Cohen and Bailey's (1997) four teams mentioned before.

1. Work teams: Work teams are work units responsible for producing goods or providing services where their membership is stable and well defined. Work teams are directed by supervisors who make most of the definitions about what is done, how is it done, and who does it. Self-managing or semi-autonomous or empowered work teams are special alternative form of work teams where employees involve in making decisions without the need of supervisors and managers. Examples for work teams include teams found in manufacturing and mining crews etc.

2. Parallel teams: Parallel teams pull together people from different work units or jobs to perform functions that the regular organization is not equipped to perform well. In other words, they literally exist in parallel with the formal organization structure and used mostly for problem solving and improvement oriented activities. Examples include quality improvement teams and task forces etc.
3. Project teams: Project teams are time-limited teams. They always produce one-time out-puts like new product or service marketing or developing a new information system or setting up a new plant etc. They are non-repetitive in nature and require considerable application of knowledge, judgment and expertise. As they always work on new products and applications, they draw their members from different departments of the organization. Thus they can also be termed as cross-functional teams.
4. Management teams: Management teams coordinate and provide direction to the sub-units under their authority and control, laterally integrating interdependent sub-units across key business processes. The management team is responsible for the overall performance of a business unit in an organization. Most of the time they are composed of managers responsible for each sub-unit. Examples include strategic development teams of any organization that gives a competitive edge over its competitors.

**2.4 Team Elements**

McGrath (1984) proposed a conceptual framework for the study of groups in which he proposes group interaction process is the central piece of the conceptual group model, as the essence of group lies in the interaction of its members in some recognized relation to one another. In other words, the communication process can be regarded as an important element. Similarly other elements of teams like coordination and work organization, which consists of task allocation or task distribution, are also very important dimensions or elements for measurement of team performance (McIntyre and Salas, 1995). The importance of coordination and communication processes increases as the task interdependence increases (Saavedra, Early, and Linn Van Dyne, 1993). Though several elements have been evaluated over the years to impact team performance, this literature review considers only coordination, communication and work organization as these three team elements are useful in defining the team task-complexity space and dimensions.

### 2.4.1 Coordination

Malone and Crowston (1994) define coordination as “managing dependencies between activities”. Other researchers such as Guastello and Guastello (1998) say that “Coordination occurs when two or more people do the same or complementary tasks at the same time”. Cooperation and collaboration are two lose words that many people think are the same as coordination. Cooperation implies shared goals among different members where as collaboration more implies peers working together on some intellectual and tactical endeavor. In fact, collaboration needs some form of coordination. The reason for pointing them out is to clarify any confusion that exists among these words. In today’s world of collaborative teams, interaction may not and probably will not be accomplished through face-to-face interaction. Thus how coordinated activities are achieved becomes of interest. The type of coordination necessitated may ultimately depend on the task to be accomplished. Coordination is supported by a number of processes such as implicit and explicit learning processes of acquiring the understanding among team members and communication process (Guastello and Guastello, 1998). However communication processes will be discussed as a separate section as it is helps in achieving coordination but it aids many other teams elements such as group decision-making.

**Implicit and explicit learning:** Implicit and explicit learning processes help in acquiring the understanding among team members. "Implicit learning is essentially an unconscious thinking process that is coupled with an explicit-learning set" (Guastello and Guastello, 1998). Implicit learning occurs to a greater or lesser extent compared with explicit learning depending on the salience of the information to be learned and the selectivity of the learner. In general, coordination will consist of both explicit and implicit components. The explicit component is to observe and understand other members' task and perform ones assigned tasks. Thereby going towards achieving the common goals and tasks of the team. Implicit learning is more like one's expectation of the other team members acts coupled with the experience gained over a period of time working in a team. In order to achieve coordination in a group or team, each member provides stimuli and some sort of feedback for the others in addition to the feedback associated with the explicit task performed.

From the team literature, implicit and explicit learning process in a broad sense could be expressed either as team situational awareness or shared mental models. Researchers such as Orasanu and Salas (1993), who focused the cognitive processes associated with teamwork, hypothesized that team members may develop and rely on shared mental models to enhance coordination and ultimately improve team performance. Shared mental models are nothing but organized bodies of knowledge that are shared across members of the team (Salas et al., 1995). Team situational awareness is nothing but sharing of a common perspective among team members regarding current environmental events, their meaning and about future status (Wellens, 1993). So it is more or like shared mental models mingled with current situation. Situation could be an environmental situation, solving a new group problem etc. Team situational awareness is made of individual situational awareness and team process that team members use to build and exchange information and enhance team coordination (Salas et al., 1995).

Research in the broad area of cognitive psychology suggests that knowledge of the interrelationships between the concepts in a domain is a critical variable that influences initial learning, subsequent retention, and later knowledge transfer. In order to work together successfully teams must perceive, encode, store, and retrieve information available for each individual team member. Thus the quality of a team's output will depend not only on the information available to the individual team member but also on the shared or team mental model (Langan-Fox, Code and Langfield-Smith, 2000). The utility of this implicit and explicit learning or shared/team mental models or situational awareness is thought to stem from its utility in providing team members with a set of organized expectations for team performance from which timely and accurate predictions about the task and team can be drawn (Cannon Bowers et al., 1995). Such knowledge could form the basis of team functioning by providing an understanding of teamwork skills and team goals. In other words, improved team coordination will further lead to good team performance. Recently a new term "team knowledge" is in greater usage. Team knowledge can be defined as the collection of task- and team-related knowledge held by teammates and their collective understanding of the current situation (Cooke, Salas, Cannon-Bowers, and Stout, 2000).

### 2.4.2 Communication

Communication is perhaps the most important process used to manage dependencies (Harvey and Koubek, 2000). Communication has been defined as clearly and accurately sending and acknowledging information, instructions, or commands (Brannick et al., 1995). Teams generally consist of members from many different disciplines and parts of the organization to share information and ideas. Since each team member has different backgrounds, knowledge, and expertise, difficulties can arise due to communication ineffectiveness and communication lapses. It is evident from several reports that communication can be the downfall of complex engineering projects (Boeing, 1999; NASA, 1999). Thus in a team, communication is an important element as it contains information relevant to completing team tasks or contains socio-emotional information about either team members or about outside people not in the team (Arrow, McGrath, and Berdahl, 2000). Any error in processing the information provided in the team communication is a very important team performance measure. If the team is working under a complex and dynamic collaborative situation any misinterpretation can cause devastating effects upon its failure. According to Brannick et al. (1995), teams that were proficient in communication acknowledged members' speech, accurately sent and received information and informed other teams of their mission progress. Teams have to identify and solve many problems while performing their task and to reach overall team goal(s) that necessitates decision-making. Decision-making is an inevitable part of the group processes and in order to understand the complexities of decision-making, communication in general will first be evaluated. Since most of the present day teams work as geographically distributed when compared to traditional teams, we need to identify the different communication patterns other than face-to-face communications. Literature related to teams and groups has shown that communication is fundamentally affected by medium through which the team members interact (Carey and Kacmar, 1997).

Communication media affect group functioning in large part by the degree to which they transmit social context cues (Straus and McGrath, 1994). Communication patterns other than face-to-face communications will cause a loss in the visual cues (Example: emotions, physical expressions), verbal cues and behavioral cues. Because of this reason, alternative communication modes such as video conferencing and computer-mediated communications need to have greater degree of clarification. However, distributed teams have been found to be more argumentative and display less consensus concerning their decisions (Hammond, Koubek, and Harvey, 2001).

### 2.4.3 Work Organization-Division of Labor

To accomplish some complex tasks teams face two issues: how to divide up the labor, and how to coordinate their efforts. In any organization this division of labor and its coordination is attributed mainly to its organizational structure. Many theories of organizational structures are proposed and used in different organizations. Some examples are matrix, project and hierarchical organizational forms.

There are two aspects of division of labor (Mintzberg, 1992). First, there are technical aspects of the task which determine in what way and to what extent you can break up the task into subtasks that can be performed by a single person. This often determines what jobs or positions may exist in the organization. There is some discretion here, but in general there is not a lot that an organization can do to change how this is done short of adopting a different technology altogether. Second, there is the allocation of people to jobs. People have different competencies, and are better placed in certain jobs rather than others. They also have different interests, and so have different levels of motivation for different jobs. Placing people in the right jobs is a crucial strategic issue.

As organizations enter the 21$^{st}$ century, the source of competitive advantage is increasingly human resources. This may sound strange in a technological age where machines do more and more of the work, but it is precisely technology that creates this dependence on human resources. This is because technology is knowledge-driven. It is all about understanding how things work and being able to exploit that knowledge to solve client problems. The most important resource most organizations have is human smarts. Given that the key problem in division of labor is the assignment of people with certain competencies and interests to tasks, part and parcel of the division of labor is the notion of specialization (Mintzberg, 1992).

### 2.5 Typology of Tasks: A Literature Review

With 'teams' comes the 'task' that they need to perform in order to solve the organizational problems. That's why some early researchers treated teams as vehicles for performing tasks (Arrow, McGrath, and Berdahl, 2000). Because task performance was central to these early researchers, a part of their research dealt with the effects of different types of tasks on performance of the teams (e.g., Kent and McGrath, 1969; Steiner, 1972; McGrath, 1984). Since teams engage in many different collective activities, a number of task typologies and descriptions have been presented in the team related literature in an effort to better define and understand the critical role of the tasks and the associated team processes.

While not exhaustive, this section will present a short discussion of many of the important task typologies that have been proposed in the psychological, small groups, communication, and information systems literature. The frameworks are presented in a chronological order with the method used and/or the name of the author(s) who proposed or popularized each system. The frameworks are useful for understanding how tasks can be classified and distinguished.

#### 2.5.1 Intuitive Classification Method – Roby and Lanzetta

Roby and Lanzetta (1958) proposed one of the first useful task classification systems. Their approach to classifying tasks required first an analysis and definition of the properties of the task. This is called intuitive classification method. They suggested two properties,

1. Objective properties – represents inherent and quantifiable task characteristics
2. Modal properties – represents those typical behaviors that groups or individuals exhibit while processing the task.

They also suggest that a task classification should involve a description of the properties of the relationships between critical task events (e.g., between input and output activities). Three properties were proposed:

1. Descriptive aspects – the qualitative and quantitative nature of the events
2. Distribution – The physical relationship among the events
3. Functional behavior – the occurrence of the events over time

Based on these properties, critical task demands or behavioral requirements can be identified as well as used to classify and distinguish between tasks.

The importance of this task typology is that it represents one of the first systems for quantifying tasks based on both objective task characteristics and behavioral requirements. Later, a good number of task typologies, particularly those of Hackman (1969), McGrath (1984), and Wood (1986), were built on this system.

### 2.5.2 Task Description and Classification Method – Hackman

Hackman (1969) proposed a framework for examining how individuals process tasks. Hackman examines three issues related to understanding experimental tasks: 1) issues associated with defining the components and characteristics of an adequate task definition; 2) issues associated with understanding what are the most appropriate bases for making task descriptions and comparisons; and 3) issues associated with understanding task effects (i.e., how task factors influence how people think and behave).

Hackman (1969) reviewed and synthesized four frameworks for task descriptions originally proposed by McGrath and Altman (1966) and Ferguson (1956). The four frameworks are labeled task qua task, task as behavior requirement, task as behavior description, and task as ability requirement. A description of these task definitions is presented in Table 2.1. After thoroughly reviewing these methods for describing tasks, Hackman came to a conclusion that the task as behavior requirement represents the best basis for defining tasks. Since it differentiates tasks based on the critical behaviors required for success that remain relatively constant for a task across subjects. The task as behavior description and task as ability requirement approaches are unsuitable since they rely on characteristics of task performers that vary across individuals for any one task. He also finds that the task qua task approach is unsuitable because an almost infinite number of potential stimuli and task dimensions exist which makes it difficult to identify which characteristics should be used to define the task.

**Table 2.1 Task Description Frameworks (Hackman, 1969)**

| |
|---|
| **Task Qua Task:** What pattern of stimuli are impinging on the subject? These are the objective dimensions of the task such as the physical nature of the task, its matter, characteristics of the stimuli. |
| **Task As Behavior Requirements:** What responses should the subjects emit, given the stimulus situation, to achieve some criterion of success? These are the critical success factors that are needed to complete the task successfully. |
| **Task As Behavior Description:** What responses does the subject actually emit, given the stimulus response? These are the actual behaviors that people engage in when they are confronted with the task. |
| **Task As Ability Requirement:** What are the patterns of personal abilities or traits, which are required for successful task completion? These are the individual physical, psychological, and background characteristics, which are necessary for successful job performance. |

Hackman's definition of task is as follows:

"A task may be assigned to a person (or group) by an external agent or may be self generated. It consists of a stimulus complex and a set of instructions, which specify what is to be done vis a vis the stimuli. The instructions indicate what operations are to be performed by the subject(s) with respect to the stimuli and/or what goal is to be achieved" (p.113).

The three important components of this definition are 1) the stimuli present in the task, 2) the instructions about operations, and 3) the instructions about goals. From this conceptualization, combined with the notion that individuals will redefine tasks, Hackman proposed a framework for analyzing how individuals' process tasks (see Figure 2.1). This framework attempts to map the 1) inputs, which are brought into a task scenario (e.g., the task stimuli, instructions, individual characteristics), 2) the redefinition process (individual interpretation of the task), 3) the development of strategies and tactics for completing the task, 4) execution of the task, and 5) the impact task execution on outcomes, perceptions, and learning.

### 2.5.3 Categorization Scheme Method – Steiner

Steiner (1972) viewed task as one of the key determinants of a group's productivity. His classifications of task focused on the outcome that was to be accomplished and the task imposed constraints that governed the means of accomplishing the outcome. A summary of Steiner's task typology is presented in Table 2.2.

This view of group tasks distinguishes between unitary tasks, where mutual assistance is infeasible, and divisible tasks that can be achieved through a division of labor. Steiner takes a normative view in which tasks are extensively described in terms of maximizing and optimizing the group's product. A group's maximum productivity is referred to as its potential productivity.

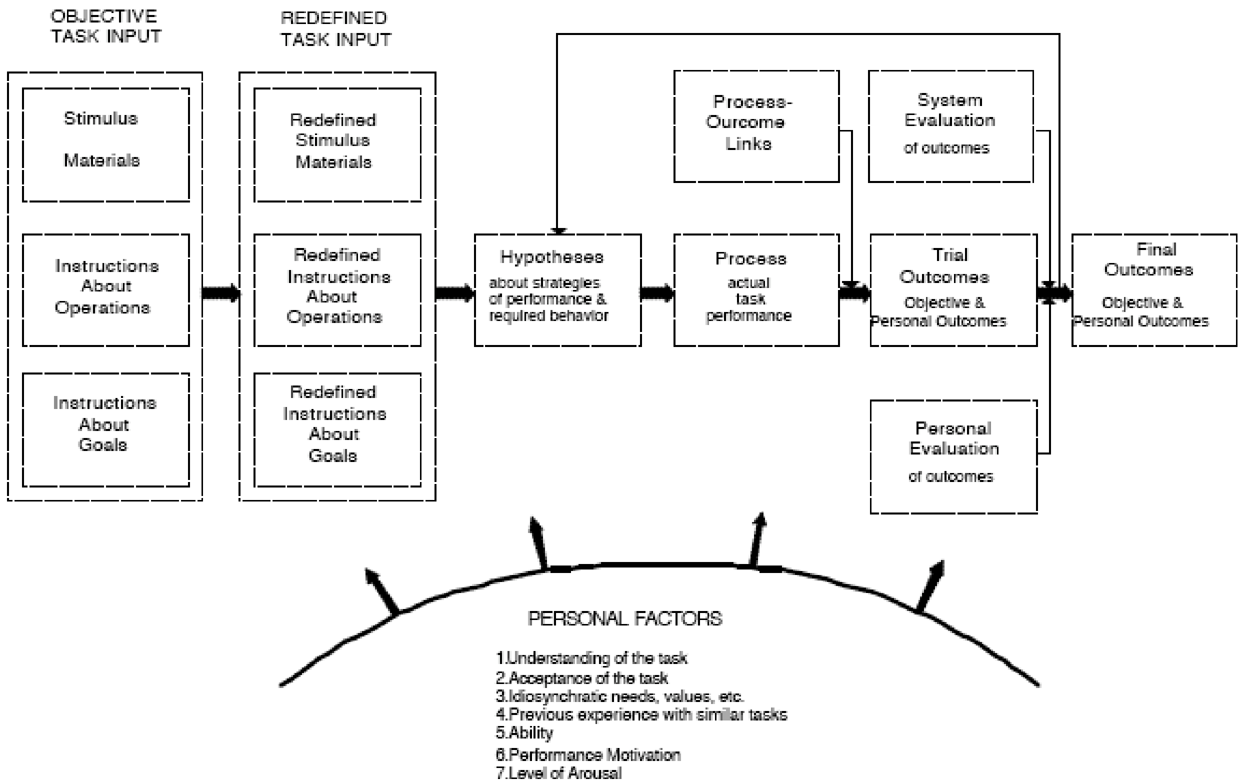



**Figure 2.1 Hackman's Task Framework (Hackman, 1969)**

This potential productivity represents the most effective use of the group's resources (e.g., member knowledge, skills, and coordination).

According to Steiner, however, a group's actual productivity may be less than its potential productivity because of faulty processes:

Actual Productivity = Potential productivity – Losses due to faulty processes (1)

Processes are the "actual steps taken by an individual or group when confronted by a task," (p. 8). This view of group performance and task asserts that a group's performance is contingent on 1) the group's resources and 2) the process of collecting those resources to address the task. Table 2.2 also lists Steiner's key determinant(s) (resource, process, or both) of productivity for each type of task.

**Table 2.2 Steiner's Task Typology (Steiner, 1972)**

| UNITARY TASKS: | DETERMINANT(S) OF GROUP PRODUCTIVITY |
|---|---|
| Disjunctive | *PROCESS:* Optimally choosing the most productive member's input as the group's sole product |
| Conjunctive | *RESOURCE:* The group's product is limited to the contribution of the least proficient member |
| Additive | *RESOURCE/PROCESS:* The group's product is an equally weighted sum of the member's contributions |
| Discretionary | *PROCESS:* The group can chose how to weight the contributions of its members in determining the group's product; (determinant is choosing an optimal weighting scheme) |
| **DIVISIBLE TASKS:** | **DETERMINANT(S) OF GROUP PRODUCTIVITY** |
| Self-matching/ Specified sub-tasks | *PROCESS:* Optimally matching sub-task requirements to the most proficient member |
| Self-matching/ Unspecified sub-tasks | *PROCESS:* Optimally identifying sub-tasks and matching those sub-tasks to the most proficient member |
| Specified matching Specified sub-tasks | *PROCESS:* Appropriateness of the role assignments and the adequacy with which members perform their assigned role |
| Organizational decisions (unspecified matching/sub-tasks) | *PROCESS:* Appropriateness of the self-selected group organizing process to the task |

### 2.5.4 Typology of Tasks Method – Laughlin

Laughlin (1980) and colleagues (Davis, Laughlin, and Komorita, 1976) have formulated a typology of tasks, which classifies tasks based both on the activities that groups are undertaking as well as the relationship between the actors. For instance, they distinguish between tasks that are carried out by cooperating groups and those conducted by groups, which are competing (i.e., mixed-motive groups). For cooperating groups, they distinguish between intellective and decision-making tasks.

Intellective tasks possess a demonstrably correct solution (i.e., the solution can be measured and evaluated in terms of its correctness) while decision-making tasks involve the development of solutions, which are not demonstrably correct (i.e., an objective measure of correctness is not available and preference among alternatives is a matter of individual or subjective assessments). In summary, an intellective task requires that the group attempt to discover the correct solution while a decision-making task requires that group members align individual preferences to reach an agreement.

Tasks, which are performed by mixed-motive groups, are split into several categories. For instance, a distinction is drawn between bargaining tasks and negotiation tasks with the former involving an attempt to resolve differences related to an individual issue or concept and the latter involving a more complex process of resolving differences related to multiple issues. Other mixed-motive tasks include those, which involve coalition formation and those, which might be called prisoner dilemma-type problems. Tasks that involve coalition formation are, for example, often structured to examine how differential payoffs for various members of a group influence the development of subgroups. Prisoner dilemma problems involve a class of dilemma problems where participants are given, either explicitly or implicitly, a pay-off matrix for either competing or cooperating with other participants.

### 2.5.5 Typology of Tasks Method – McGrath's Task Circumplex

McGrath (1984) proposed what he termed a Task Circumplex by integrating the work of Hackman and Morris (1975, 1978), Laughlin (1980), Shaw (1973), Davis (1980), and others into a conceptually and visually elegant framework for classifying group tasks (see Figure 2.2 and Table 2.3).

Hackman (1968) and Hackman and Morris (1975, 1978) identified production (generate alternatives), discussion (dealing with issues), and problem-solving (generating plans for action) task types based on the behavioral and performance processes required to complete the task (i.e., using the task as behavior requirement framework). McGrath built on Hackman's observations and described four general processes (depicted as quadrants): generate, choose, negotiate, and execute. Within these general processes he incorporated more specific sub-tasks based on the task qua task framework. For example, the model includes Laughlin's (1980) distinction between intellective tasks, which have a demonstrably correct answer, and decision-making tasks, which have no correct answer but rely on group consensus.

McGrath designed the Task Circumplex categories to be 1) mutually exclusive between categories, 2) collectively exhaustive, 3) logically related, and 4) useful for comparing similarities and differences of various tasks used in group research. The circumplex is divided on two dimensions: the horizontal axis defines the conceptual/behavioral dimension while the vertical axis defines tasks in terms of conflict/cooperation. These axes are defined using the task as behavior description framework since these axes define, at least in part, behaviors which are likely to be produced by the tasks which project on these behavioral dimensions. An important limitation of the circumplex is that it does not provide a means for objectively measuring the degree to which tasks in each wedge of the circumplex differ both from tasks within the same category and also in other categories.

Researchers like Wood (1986), Campbell (1988) and Bystrom and Jarvelin (1995) developed task complexity models to differentiate the tasks. But it is Harvey (1997, 2001) who integrated these models together and proposed a team task-complexity space consisting of three task-complexity dimensions (task-scope, task-structurability, and task-uncertainty). Any team tasks could be represented easily in Harvey's team task-complexity space. But Harvey's team task-complexity space is yet to be proved and tested whether any team task complies with the three proposed task-complexity dimensions or not?

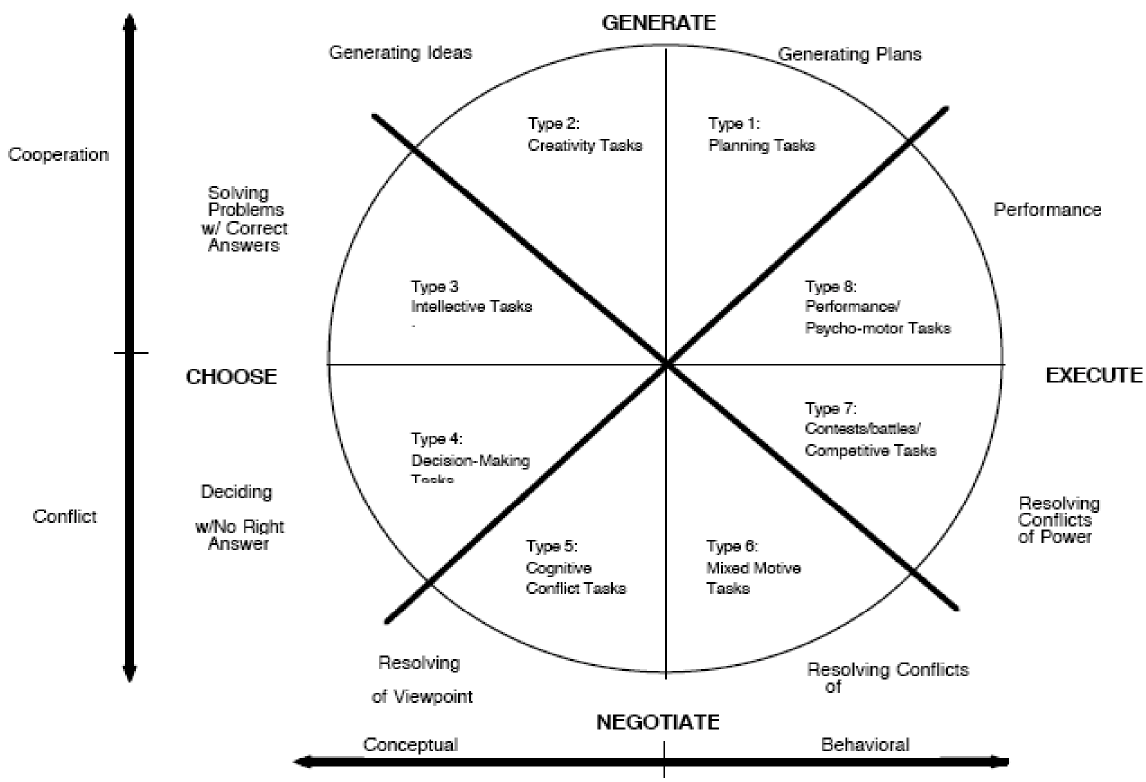



**Figure 2.2 McGrath Task Circumplex (McGrath, 1984)**

**Table 2.3 Description of McGrath's Task Categories (McGrath, 1984)**

| | |
|---|---|
| **QUADRANT 1** | **GENERATE** |
| Type 1 | *Planning Tasks:* Generating plans; Key notion: Action-oriented plan |
| Type 2 | *Creativity Tasks:* Generating ideas; Key notion: Creativity |
| **QUADRANT 2** | **CHOOSE** |
| Type 3 | *Intellective Tasks:* Solving problems with a correct answer; Key notion: Correct Answer |
| Type 4 | *Decision-making Tasks:* Dealing with tasks for which the preferred or agreed upon answer is the correct one; Key notion: Preferred answer |
| **QUADRANT 3** | **NEGOTIATE** |
| Type 5 | *Cognitive Conflict Tasks:* Resolving conflicts of viewpoint; Key notion: Resolving policy conflicts |
| Type 6 | *Mixed-Motive Tasks:* Resolving conflicts of motive-interest; Key notion: Resolving pay-off conflicts |
| **QUADRANT 4** | **EXECUTE** |
| Type 7 | *Contests/Battles:* Resolving conflicts of power; competing for victory; Key notion: Winning |
| Type 8 | *Performances:* Psychomotor tasks performed against objective standards; Key notion: Excelling |

## 2.6 Task Complexity

Tasks differ in terms of their complexity as determined by their characteristics (Prasad and Akhilesh, 2002). Task complexity has been examined within three bodies of literature according to Campbell (1988): the information processing and decision-making, task and job design, and goal-setting research literature. Within this literature, complexity is treated as: primarily a psychological experience, an interaction between task and person characteristics, and a function of objective task characteristics. Wood (1986) stated that many of the complexity definitions combine task and non-task elements thereby complicating their use for different tasks within different environments. In order to identify the components of the task that would represent behavior independent of complexity and describe the task and individual's characteristics of the task. Harvey (1997, 2001) came-up with an ideology of an integrative framework for task complexity (Wood, 1986; Campbell, 1988; Byström and Järvelin, 1995). Prior to delving into task complexity, it seems significant to understand what defines a task.

While Steiner says a task is anything that must be done to accomplish some purpose, Wood (1986) defines a clearer framework for defining tasks. Every task, according to Wood, is composed of three components: products, (required) acts, and information cues. Products are defined as the entities created or produced through behavior or acts that are independent of the goals and expectations of the individuals who performed the task. Acts are defined as the pattern of behaviors that have a definable purpose toward the creation of the product. The third element, information cues, is the pieces of information used by an individual to make judgments during the performance of a task. Therefore any definition of complexity must incorporate an analysis of at least these three elements.

The starting point to define the concept of team task complexity will be drawn from Harvey (1997, 2001). Harvey draws from existing literature (Daft and Macintosh, 1981; Wood, 1986; Campbell, 1988; Campbell, 1991; Byström and Järvelin, 1995; Chen and Lin, 2003) and creates a comprehensive definition of complexity along three primary characteristics: scope, structurability, and uncertainty. Since the task forms the foundation by which teams collaborate, quantifying tasks is essential to allow researchers to compare experimental results.

The task scope is the breadth, extent, range, reach, or general size of a task. The scope is a function of the sub-tasks, outcome(s), information processed, and the outcome characteristics and their conflicting objectives. Each task can be decomposed into sub-tasks. A sub-task has identifiable behaviors or steps with an identifiable purpose or direction (McGrath, 1991). Outcomes are the entities created that result from activities of the collaborative individuals and are independent of the behaviors used to produce them. For each outcome, there exists a set of characteristics by which its success is measured. Outcome characteristics include the attribute, aspect, property, quality, or trait of an outcome. Characteristics may conflict with each other and thus increase the complexity of the task. For example, altitude and accuracy may conflict with each other in an aerial intelligence seeking information task. The last element that defines the task scope is information. Information is the amount of required knowledge in the accomplishment of the task.

With this basic understanding of a task and its scope, the other two dimensions can be explained. Task structurability represents how well defined the sequence and relationships between subtasks are, and are determined by the elements analyzability, alternatives, and coordination. Analyzability reflects the degree of consistency between sub-tasks and their outcomes. If characteristics reflected by an outcome can be reached in more ways than one, the number of paths to reach it is summed as task alternatives. Moreover, if task accomplishment is contingent on coordination among sub-tasks, the number of relationships required is counted as task coordination. Chen and Lin (2003) identify three information flows in complex tasks: independent (uncoupled), dependent (decoupled), and interdependent (coupled). Interdependent tasks require more interaction by the team and thus are likely to make team task completion difficult.

The task uncertainty dimension attempts to measure complexity based on the degree of predictability or confidence associated with a task. Internal confidence indicates the degree of certainty or predictability of the structure established among tasks, alternatives, sub-tasks, and characteristics. External events include changes in the set of required product characteristics that are imposed by higher echelons of command. It is worth noting that random events have been included since these chance events can ultimately affect a task's complexity.

Using the defined task features, one might suggest that a three-dimensional team complexity space exists where vastly different team environments can be placed (refer to Figure 2.3). Table 2.4 details each of the features of the task taxonomy within the three dimensions as proposed by Harvey (1997, 2001).

**Table 2.4 Task Features Proposed to Impact Complexity (Harvey, 2001)**

**Task Scope**

1. Sub-tasks: decomposed components of the task for which there are behaviors or steps with an identifiable purpose — complexity increases as the number of subtasks increase (Steiner, 1972; Wood, 1986)
2. Products: products (or sub-components) that result from the task — complexity increases as the number of products increase unless they are related or reused sub-components (Wood, 1986) (Campbell, 1988)
3. Product Characteristics: characteristics by which the success of the product is measured (i.e., quality, time to delivery, flexibility of modification, cost, weight, etc.) — complexity increases as a function of the number of characteristics (Campbell, 1988)
4. Characteristic Conflicts: presence of conflicting product characteristics (i.e., quality vs. speed) — complexity increases as a function of the number of conflicting characteristics (Campbell, 1988)
5. Information: amount of information processed in the accomplishment of the task — complexity increases as the amount of information to be processed increases (Wood, 1986) (Campbell, 1988)

**Task Structurability**

Analyzability: the ability to create sub-task relationships and identify the cause and effect

(table cont'd.)

relationships between sub-tasks and their outcome — complexity increases as the task analyzability decreases (Daft and Macintosh, 1981)

Alternatives: multiple paths to reach the desired product characteristics — complexity increases as a function of the number of paths that can be taken to arrive at the product (Campbell, 1988)

Coordination: relationships between sub-tasks in the accomplishment of the task — complexity increases as a function of the number of coordination information flows increases for a task (e.g., independent, dependent, or interdependent) (Wood, 1986; Chen and Lin, 2003)

**Task Uncertainty**

1. Internal Confidence: the degree of certainty or predictability of the structure established among tasks alternatives, sub-tasks, and characteristics — complexity will increase when the links between sub-tasks and alternatives and sub-tasks and task characteristics cannot be established with certainty (Campbell, 1988)
2. External Constraints: changes in the set of required product characteristics that are organizationally imposed — complexity increases as a function of the amount of changes (Wood, 1986)
3. Random Events: chance occurrences or irregular events that take place during the course of a task which disrupt its completion — complexity increases as the number of unexpected events increases (Daft and Macintosh, 1981)

## 2.7 Team Performance

The first and foremost concrete work that resulted in evolution of team performance model was of Nieva, Fleishman and Rieck (1978), which is based on an extensive review of the group performance literature. According to their findings, team performance has two primary components.

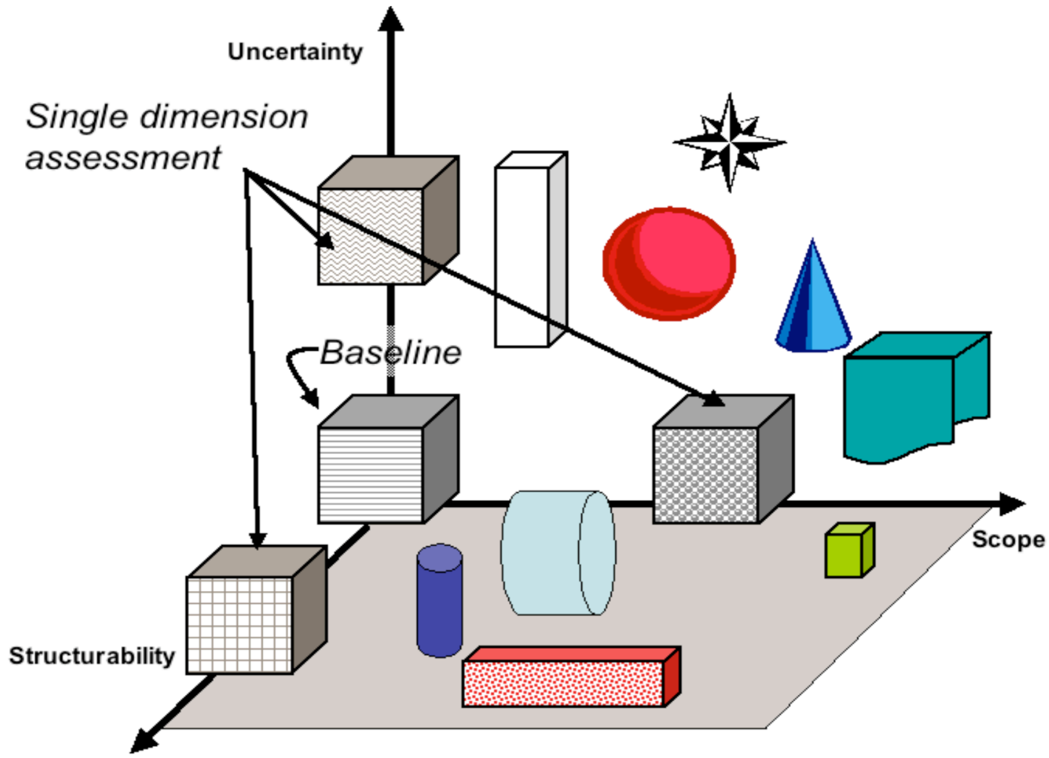



**Figure 2.3 Team Task Complexity Profiles (Rothrock, Harvey and Burns, 2005)**

They are,

1. Individual task behaviors – the behaviors requiring no coordination among team members
2. Coordinated task-related processes, functions, and behaviors – all the behaviors that promote coordination among team members and sub-tasks.

The above two components combine to determine the level and nature of the team performance. However the weight of each component's contribution to team performance varies according to nature of the particular task characteristics. They also identified four classes of variables: external conditions, member resources, team characteristics, and task characteristics and demands. These variables are useful in determining the time needed to complete the task, the critical requirements and member resources that combine to form relationships etc for successful team performance. To fully understand these variables that relate to team performance, Nieva, Fleishman and Rieck (1978) proposed taxonomy of team functions. Later Fleishman and Zaccorro (1992) prepared an extensive taxonomy of team functions consisting of seven functions. They are,

1. Orientation Functions – the processes used by team members in information exchange needed for task accomplishment.
2. Resource Distribution Functions – processes used to assign members and their resources to particular task responsibilities.
3. Timing Functions – organization of team activities and resources to complete the tasks within time frame and temporal boundaries.
4. Response Coordination Functions – coordination and integration and synchronized member activities.
5. Motivational functions – definition of team objectives/goals and motivational processes for members to achieve the proposed objectives.
6. Systems Monitoring Functions – error detection in the team as a whole and individual members
7. Procedure Maintenance – maintenance of synchronized and individual actions in compliance with established performance standards.

By means of these seven team functions, one could easily understand the team performance measurement tools used by many researchers such as Observational Scales (Smith-Jentsch, Tannenbaum, and Cannon-Bowers, 1995), critical incidents-based observational protocols (e.g. Johnston, Smith_jentsch, and Cannon-Bowers, 1997), expert opinion (e.g., in the form of rating scales; see Borman, 1991), TARGET methodology and checklists (Fowlkes et al., 1994), Anti-Air Warfare Team Performance Index (Johnston, Smith-Jentsch, and Cannon-

Bowers, 1997). These team performance measurement tools take goal accomplishment, accuracy, number of errors and accomplishment time into account for calculating team performance (Cannon-Bowers and Salas, 1997).

However most of these measurement tools are subjective in nature and are developed in relation to military teams and training. The problem with subjective team performance measures is that it is cumbersome and time-consuming process. In general, when team performance is assessed, the evaluation methods rely on instructors or other subject matter experts (SMEs) to provide numerical ratings of performance (Modrick, 1986). According to Dwyer et al. (1997), rating scales, though carefully constructed, have several deficiencies that limit them as evaluation tools. First, they lack diagnostic specificity, as they do not point out specific performance deficiencies. Second, rating techniques usually require highly trained subject matter experts (SMEs) to achieve adequate measurement properties. Thus one cannot relate and compare the results from different teams in different contexts. Especially for today's collaborative teams in the world of complex and technologically advanced systems, we need a more robust team performance measurement construct.

**2.7.1 Time Windows**

A proper understanding of team performance characteristics is required for designing complex systems that involve team tasks. While human factors texts provide some insights into basic performance issues, the emergence of highly automated computing systems have fundamentally altered the way humans work. Thus to quantify and analyze human performance within a complex, time-critical system we need a proper measurement construct. Time window, which enables a functional relationship between constraints on team activities and time availability, is one such measurement construct that is of great use (Rothrock, 2001).

Rothrock (2001) defines time window as a construct that specifies a functional relationship between a required situation and a time interval that specifies availability for action. The time windows formulation by Rothrock is an extension of the theory of situativity proposed by Greeno (Greeno and Moore, 1993; Greeno, 1998). A time window does not specify what action must be taken, but only that there exists an action that will result in the required situation. Using temporal logic (Allen, 1984; Gabbay, Hodkinson, and Reynolds, 1994) and a Boolean algebra, a truth maintenance system (TMS) is established to specify whether a decision maker is early, on-time, or late in taking an action. Moreover, it also specifies what actions are acceptable.

Time windows represent a belief system of required situations that are time and environment-based. Therefore, a truth maintenance system (Doyle 1979) is needed to maintain time windows throughout the timeframe of team interaction. The utility of a time window is not only in its temporal and functional descriptions, but also in the richness of the possible outcomes. The complete space of possible time window outcomes (see Figure 2.4) proposed by Rothrock (2001) is represented by the fundamental relationships between time windows and operator actions. In itself, the existence of a required situation does not impact team performance. It is the presence of operator action in a temporal context that specifies whether performance is good or poor. An action that is wrong is termed as incorrect action ((4), in Figure 2.4). A correct action, on the other hand, can be further characterized as early ((1), in Figure 4), on-time ((2) in Figure 4), or late ((3) in Figure 2.4). An action with no corresponding required situation is categorized as False Alarm ((5), in Figure 2.4). A non-action for an existing situation requirement is characterized as a miss (6). In the recent discussions with, Rothrock (2005), early correct and late correct actions can be considered as false alarms since they do not practically exist. Thus early correct (2) and late correct (3) should be categorized and placed with false alarms (5). Figure 2.5 shows modified version of the possible time window outcomes.

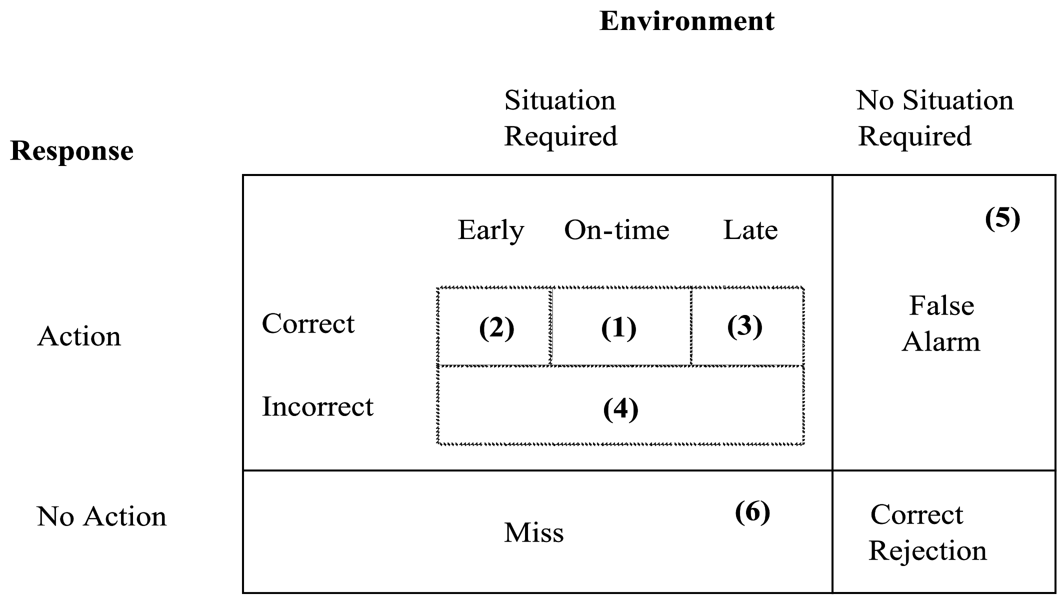



**Figure 2.4 Possible Time Window Outcomes (Rothrock, 2001)**

Note: The environment is delineated in terms of situation required (time window exists) or no situation is required (time window does not exist). 1-4 represent actions that are relevant to a time window. 1-3 represent actions that result in the required situation (correct actions). 4 represent actions that do not meet the required situation (incorrect actions) even though they are relevant.

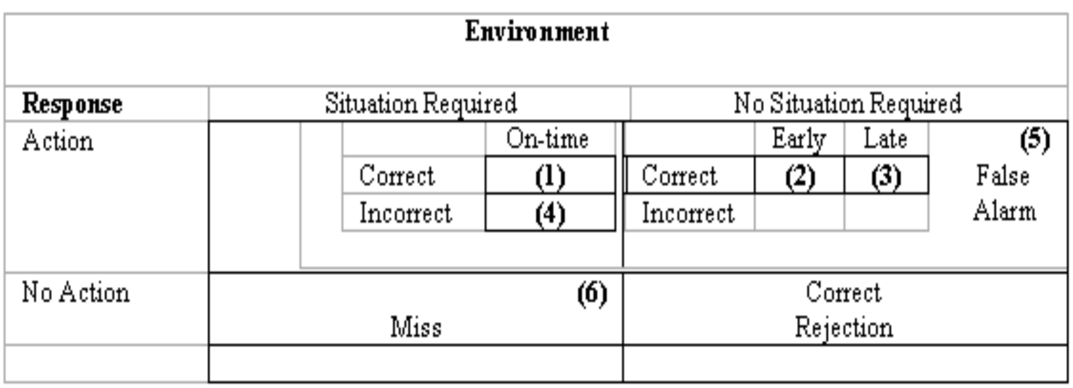



**Figure 2.5 Possible Time Window Outcomes (Rothrock, 2005)**

Note: 1 represents actions that result in the required situation (correct actions). 2-3 represent actions that fall under as false alarm. 4 represent actions that do not meet the required situation (incorrect actions) even though they are relevant.

## 2.8 Discussion

A good amount of team theory and research is based on the classic systems theory of input-process-output (Ilgen, 1999). However it was both McGrath (1984) and Hackman (1987) who described traditional small groups' research of classic systems theory terms with inputs, processes, and outputs. However the traditional input-process-output approaches tended to focus more on the development of psychological process theories (e.g. Steiner's (1972) Model of Group Process and Cooper's (1975) book on theories of group processes). Teams' tasks, contexts, and composition (on input side) often were of interest only as boundary conditions thereby restricting behaviors and contexts over which process theories generalized.

In organizations, inputs like task characteristics and outputs like task performance, are more important and critical team factors (Ilgen, 1999). As organizations use more teamwork oriented approaches the importance of teams and team behaviors increases. Thus more research is focused on the identification and determination of input factors like task-context and behavioral factors that contribute to effective teamwork, and output factors like team performance.

- So it is important to have a generalized team–tasks oriented approach that conceives different teams as embedded entities in a task-space developed based on the task context, task characteristics, and task-complexity.

In today's world of collaborative teams, interaction may not and probably will not be accomplished through face-to-face interaction. Thus how coordinated activities are achieved becomes of interest. The type of coordination necessitated may ultimately depend on the task to be accomplished. Coordination is supported by a number of processes such as implicit and explicit learning processes of acquiring the understanding among team members, time-dependent information processing, and communication process (Guastello and Guastello, 1998). Though communication helps in achieving coordination but it also aids many other team elements such as group decision-making.

- Thus the generalized team–tasks oriented approach should also include coordination and communication in some way to develop the task-space.

The team performance measures developed are cumbersome in nature as well as a time-consuming process. In general, when team performance is assessed, the evaluation methods rely on instructors or other subject matter experts (SMEs) to provide numerical ratings of performance (Modrick, 1986; Dwyer et al., 1997). Thus one cannot relate and compare the results from different teams in different contexts.

- Thus the generalized team-task oriented approach should have the ability to relate and compare the results from different teams in different contexts.

In order to have such a generalized model, first a task-space has to be conceptualized. Harvey (1997, 2001) proposed one such kind of team task-complexity space (refer to section 2.6 for details) having task-scope, task-structurability and task-uncertainty as its three dimensions where team-tasks in the domain of distributed engineering design could be represented. The current research builds a conceptual model of generalized team task-complexity space based on the ideology of Harvey (1997, 2001).

# CHAPTER 3

# PROPOSED MODEL AND HYPOTHESES

## 3.1 Rationale

The literature review indicates that the research towards a generalized team–tasks oriented approach for building team task-complexity space has a good potential to help the distributed team environments. Therefore, research in this area has the scope to generate new concepts for team collaboration and to define a quantification mechanism for teams by means of new metrics. As a result, there is a possibility for new team performance measures.

From the discussion section of the literature review (see section 2.8), the generalized team–tasks oriented approach could be defined as follows,

The generalized team–tasks oriented approach is an approach that would conceive different teams as embedded entities in a task-space developed based on the task context, task characteristics, task-complexity, coordination, and communication with a strong ability to compare the results from different teams in different contexts.

In order to have such a generalized model, first a task-space has to be conceptualized. Harvey (1997, 2001) proposed one such kind of team task-complexity space (refer to section 2.6 for details) having task-scope, task-structurability and task-uncertainty as its three dimensions. Though it is a very good integrated model of task complexity, Harvey's team task-complexity space and its three dimensions are built in the perspective of distributed engineering design and is completely domain specific. At the same time it has not been completely experimentally validated and thus a generalized integrated model of task complexity still does not exit. The current research builds a conceptual model of generalized team task-complexity space based on the ideology of Harvey (1997, 2001).

After a thorough review of Harvey (1997, 2001), a summary of the following observations could be outlined,

- The task-scope sub-dimension, products, which is defined as sub-components that result from the tasks, is specific to the domains of distributed engineering design and manufacturing. Also products are dependent on the tasks and sub-tasks. Including it adds a repetitive component to the complexity taxonomy. Thus the generalized team task-complexity space cannot allocate this sub-dimension into its task-scope dimension.
- Similarly the task-scope sub-dimensions, product characteristics and characteristic conflicts, which are also specific to distributed engineering design and manufacturing, cannot be allocated in the generalized team task-complexity space.
- The task-structurability sub-dimension, analyzability, is defined as the ability to create sub-task relationships and identify the cause and effect relationships between sub-tasks and their outcome (Daft and Macintosh, 1981). However according to Daft and Macintosh (1981), the unanalyzable tasks (tasks with low analyzability) bring in the 'response' uncertainty. Therefore, this component and the uncertainty component seemed to be highly related.
- All the task-uncertainty sub-dimensions are well emphasized and are not domain specific.

Table 3.1 shows definition of the proposed task features or sub-dimensions that form of the generalized task-complexity space and dimensions.

### 3.2 Developing a Conceptual Model of Task Complexity and Team Performance

From McGrath task circumplex (1984), decision-making tasks are defined as the tasks where a correct answer is unknown. Whenever there involves some from of decision-making, team members discuss and come to a consensus after reviewing all possible options to accomplish the tasks.

**Table 3.1 Task Features Proposed to Impact Complexity**

**Task Scope**

1. Sub-tasks: decomposed components of the task for which there are behaviors or steps with an identifiable purpose — complexity increases as the number of subtasks increase (Steiner, 1972; Wood, 1986)
2. Information: amount of information processed in the accomplishment of the task — complexity increases as the amount of information to be processed increases (Wood, 1986; Campbell, 1988; Carey and Kacmer, 1997)

**Task Coordination**

1. Coordination: relationships between sub-tasks in the accomplishment of the task — complexity increases as a function of the number of coordination information flows increases for a task (e.g., independent, dependent, or interdependent) (Wood, 1986; Chen and Lin, 2003)

**Task Uncertainty**

1. Internal Confidence: the degree of certainty or predictability of the structure established among tasks alternatives, sub-tasks, characteristics and outcomes — complexity will increase when the links between sub-tasks and alternatives, sub-tasks and task characteristics sub-tasks and task outcomes cannot be established with certainty (Campbell, 1988; Perrow, 1967; Daft and Macintosh, 1981; Daft and Lengel, 1986)
2. External Constraints: changes in the set of required task characteristics that are organizationally imposed — complexity increases as a function of the amount of changes (Wood, 1986; Wood, 1988)
3. Random Events: chance occurrences or irregular events that take place during the course of a task which disrupt its completion — complexity increases as the number of unexpected events increases (Daft and Macintosh, 1981; Speier, Vessey and Valacich, 2003)

Thus decision-making brings in complexity into the team tasks (Arrow, McGrath, and Berdahl, 2000; McGrath, 1984). Further decision-making will also lead to some form of uncertainty and ambiguity, as teams have to choose one of possible solutions based on the knowledge of alternatives, knowledge of consequences (e.g. risks associated with decisions), decision rules, amount and accuracy of information available (March, 1988; March, 1991; Hollenbeck et al., 1995). From this point of view, broadly one could divide the team tasks as team tasks with uncertainty and team tasks without uncertainty. With this argument the following conclusions could be drawn,

**Team Tasks without Uncertainty:** Uncertainty is zero for team tasks without uncertainty (e.g. Intellective Tasks from McGrath, 1984). Thus it is proposed that the task-scope and task-coordination dimensions are enough to represent such team tasks, as there is no uncertainty or a negligible amount of uncertainty.

So the 2-dimensional space is enough to represent this type of team tasks. Thus, the following proposition is framed,

**Proposition 1:** Team tasks without uncertainty can be represented in a 2-dimensional task space of task-scope and task-coordination as dimensions. (e.g., intellective tasks from McGrath (1984))

**Team Tasks with Uncertainty:** Uncertainty is clearly believed to contribute to task complexity for many tasks. So the three dimensions of task-scope, task-coordination and task-uncertainty are needed to represent such team tasks.

**Proposition 2**: Team tasks with uncertainty can be represented in a 3-dimensional task complexity space of task-scope, task-coordination and task-uncertainty as dimensions. (e.g., decision-making tasks from McGrath (1984))

### 3.2.1 Task Complexity vs. Task Performance

Tasks with more complexity typically contain more information cues than tasks with less complexity. Therefore, an increase in task-complexity increases the amount of information cues to be processed, which results in some information cues not being processed and may deteriorate task performance (Wood, 1986). Consequently, the perceived workload and stress increases as the task-complexity increases and inhibit performance (Speier, Vessey and Valacich, 2003). However, it is not true for all the teams. Entin and Serfaty (1999) found that an increase in the level of task complexity and stress did not necessarily result in a decrease in the team's outcome performance. They felt that some teams are able to adapt to these conditions and reasoned that switching from explicit to implicit coordination helped them. According to Morgan and Bowers (1995), the effect of increased workload on team performance is not yet clear. However the saliency of workload factor caused by complex, dynamic and ambiguous characteristics of task environments, coupled with its known effects on individual task performance, suggests that it is likely to have a negative effect on team performance (Urban et al., 1995). After a thorough consideration of the above facts, one could state that there exists some task-complexity level after which the performance would decrease.

## 3.3 Proposed Conceptual Model: Towards A Generalized Team Task Complexity Model

Thus, this thesis proposes to define the underlying dimensions that compose a task which contribute to complexity in a team environment. McGrath's circumplex defines tasks of different notional complexities; however, his model stops short of identifying the mechanisms that compose the complexity. A more defined model would provide designers of the team tasks to clearly understand the elements that contribute to the complexity and thus allow for better design of the team tasks.

As discussed in the literature review, several dimensions potentially represent task complexity. For the purpose of this thesis, these variables are grouped into three complexity dimensions: task-scope, task-coordination, and task-uncertainty. These complexity dimensions are hypothesized to affect the teams' task performance. Figure 3.2 displays the proposed generalized team task-complexity conceptual model in concert with how it fits with McGrath's task definitions. Refer to Table 3.1 to see the definition of the proposed task features or sub-dimensions that form of the generalized task-complexity space and dimensions.

**3.4 Model Description: Generalized Model of Task Complexity Components**

The conceptual model displayed in Figure 3.1 is composed of several components and relationships. Table 3.2 identifies each major component along with the supporting literature.

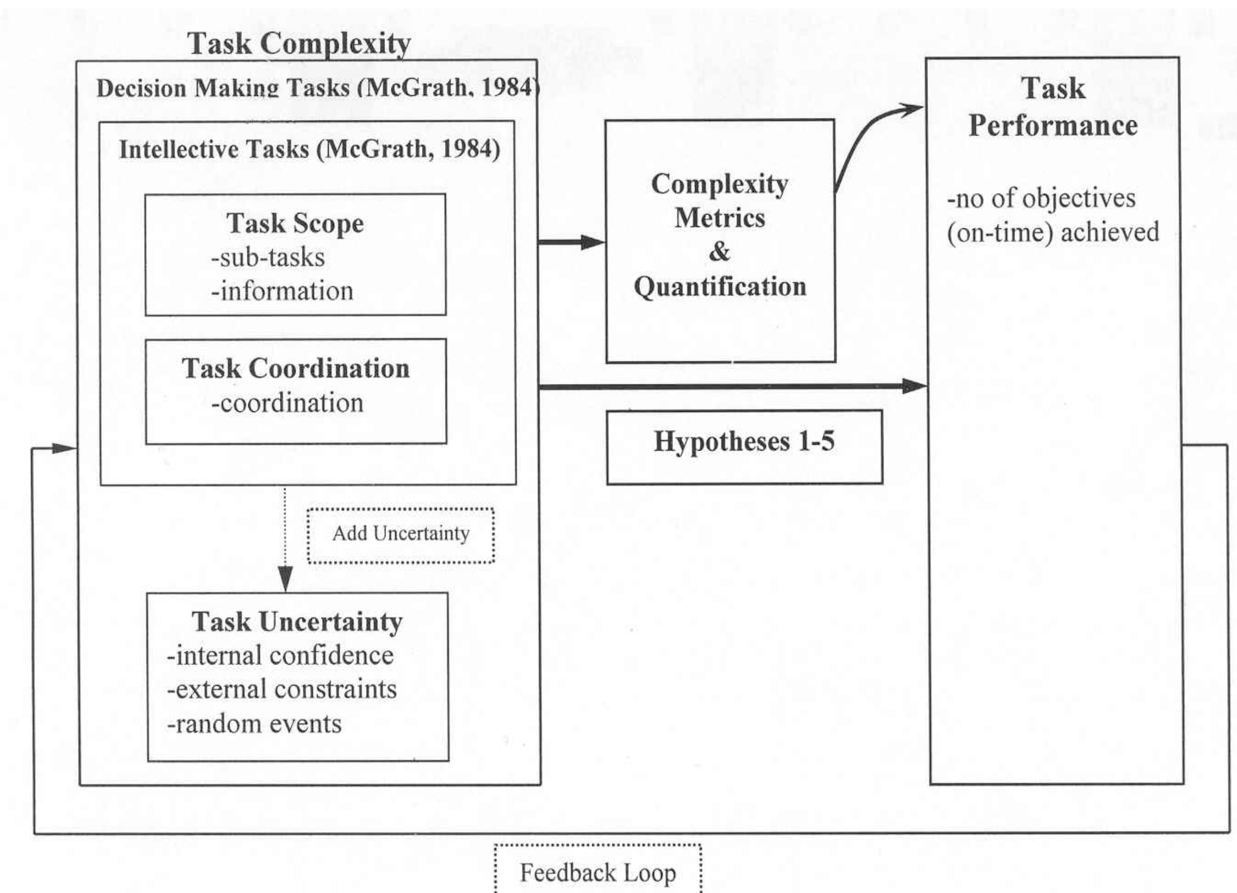



**Figure 3.1 Towards a Generalized Team Task Complexity Model**

**Table 3.2 Model Components and Supporting Literature**

| Model Components | Summary | Support for Model Assumptions |
|---|---|---|
| **Task Complexity Dimensions** | | |
| **Task Scope** | | |
| Sub-tasks | Complexity increases as the number of sub-tasks increase | Steiner (1972)<br>Wood (1986) |
| Information | Complexity increases as the amount of information to be processed increases | Wood (1986)<br>Campbell (1988)<br>Campbell (1991)<br>Carey and Kacmer (1997) |
| **Task Coordination** | | |
| Coordination | Complexity increases as a function of the number of coordination information flows | Wood (1986)<br>Chen and Lin (2003) |
| **Task Uncertainty** | | |
| Internal Confidence | Complexity will increase when the links between sub-tasks and alternatives; sub-tasks and task characteristics; and sub-tasks and outcomes cannot be established | Campbell (1988)<br>Campbell (1991)<br>Perrow (1967)<br>Daft and Macintosh (1981)<br>Daft and Lengel (1986) |
| External Constraints | Complexity increases as a function of the amount of changes | Wood (1986)<br>Wood et al. (1988) |
| Random Events | Complexity increases as the number of random events increases | Daft and Macintosh (1981)<br>Speier, Vessey and Valacich (2003) |
| **Task Performance** | Complexity increases the perceived workload and stress there by deteriorating the task performance. | Wood (1986)<br>Speier, Vessey and Valacich (2003)<br>Entin and Serfaty (1999)<br>Morgan and Bowers (1995)<br>Urban et al. (1995)<br>Carey and Kacmer (1997) |
| Previous Task Complexity Models | Some general references to task complexity research and models | Wood (1986)<br>Bystrom and Jarvelin (1995)<br>Harvey (1997, 2001)<br>Zhao (1992) |

### 3.4.1 Hypotheses for Supporting Proposition 1

Task-scope is a function of sub-tasks and information processed. In other words they are the sub-dimensions of task-scope. From the teams' literature, as the amount of information-processed increases the task complexity increases thereby the team performance will decrease after crossing a certain information load (Wood, 1986; Campbell, 1988).

Similarly, as the number of sub-tasks increases the task complexity increases thereby decreasing the team performance after crossing a certain limit (Steiner, 1972; Wood, 1986). Thus, by keeping one task dimension constant and testing a team task with various levels of second task dimension, one can validate whether team tasks would comply to the task complexity dimensions or not.

Three hypotheses are designed to validate proposition 1. One hypothesis each designed to validate and evaluate whether task-scope and task-coordination as task complexity dimensions would really affect the team task performance or not? Another hypothesis is designed to validate whether both task-scope and task-coordination contribute equally towards task complexity and team task performance.

So the list of hypotheses supporting proposition 1 are as below,

1. Difference in team task-performance exists as task complexity is increased by the task-scope.
2. Difference in team task-performance exists as task complexity is increased by the task-coordination
3. Task-scope and task-coordination, as dimensions of task complexity, do not contribute in equal proportion to the team task-performance.

### 3.4.2 Hypotheses for Supporting Proposition 2

Task-uncertainty is a function of internal confidence, external constraints and random events. In other words, they are the sub-dimensions of task-uncertainty. From the teams' literature,

- Task complexity increases when the links between sub-tasks and alternatives, sub-tasks and task characteristics and sub-tasks and outcomes cannot be established with certainty there by decreasing the team performance after crossing certain level. (Campbell, 1988; Campbell, 1991; Perrow, 1967; Daft and Macintosh, 1981; Daft and Lengel, 1986)
- Task complexity increases as a function of the amount of changes in external events there by decreasing the team performance after crossing certain level. (Wood, 1986; Wood et al., 1988)
- Task complexity increases as occurrence of unexpected or random events increases there by decreasing the team performance after crossing certain level. (Daft and Macintosh, 1981; Speier, Vessey and Valacich, 2003)
- Thus, testing a team task with various levels of task-uncertainty dimension one can validate whether it really acts as a task-complexity dimension or not?
- Similarly validation is needed to know whether the three task complexity dimensions would really affect and contribute equally towards team task performance or not?

Thus, two hypotheses are designed to validate proposition 2. One hypothesis is designed to validate and evaluate whether task-uncertainty as a task complexity dimension would really affect the team task performance or not? Another hypothesis is designed to validate whether the three task complexity dimensions (scope, coordination and uncertainty) contribute equally towards the task complexity and team performance or not?

So the list of hypotheses supporting proposition 2 are as below,

1. Difference in team task-performance exists as task complexity is increased by the task-uncertainty
2. Task-scope, task-coordination, and task-uncertainty, as dimensions of task complexity, do not contribute in equal proportion to the team task-performance.

Objective of the proposed generalized team task-complexity model is to define and validate the underlying dimensions that compose a task which contribute to complexity in a team environment. Thus, main objective is to validate the three task-complexity dimensions and evaluate how they affect the team task performance.

So from the discussion of hypotheses supporting proposition 1 and 2, hypotheses are numbered in the order of importance.

**Hypothesis 1:** Task scope, coordination, and uncertainty, as dimensions of task complexity, do not contribute in equal proportion to the team task-performance.

**Hypothesis 2:** Task scope and task coordination, as dimensions of task complexity, do not contribute in equal proportion to the team task-performance.

**Hypothesis 3**: Difference in team task-performance exists as task complexity is increased by the task-scope.

**Hypothesis 4:** Difference in team task-performance exists as task complexity is increased by the task-coordination.

**Hypothesis 5:** Difference in team task-performance exists as task complexity is increased by the task-uncertainty.

# CHAPTER 4

# METHOD

The purpose of this section is to describe the methods, procedures, and analysis that are used to test the previously defined hypothesis. The experimental design, subjects, equipment, experimental task, and procedure for experiment will be discussed in detail. Each hypothesis, including its independent, and dependent variables, will be reviewed along with the appropriate analysis technique.

## 4.1 Experimental Design and Layout

As proposed in the generalized team task-complexity model, the task-complexity depends on three dimensions (factors) namely task-scope, task-coordination and task-uncertainty. Therefore, in this case a multiple linear regression analysis is necessary to capture the contribution of each dimension towards complexity and performance. Thus, the general problem of fitting the model is,

$$Y = \beta_0 + \beta_1 S + \beta_2 C + \beta_3 U + \beta_4 S*C + \beta_5 C*U + \beta_6 S*U + \beta_7 S*C*U \qquad (2)$$

Where,

Y = Team task-performance

S = Task Scope

C = Task Coordination

U = Task Uncertainty

$\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6$, and $\beta_7$ are regression coefficients.

As the exact behavior of the three dimensions (factors) of task-complexity is not completely known, a $3^3$ full factorial design is an appropriate design of experiment (DOE) in the present proposed generalized team task-complexity theory. After getting enough participant teams, the initial idea of running a reduced model of 20 data scenarios generated by a D-optimal design was put aside, and the full $3^3$ factorial design model is used. Thus $3^3$ full factorial design (3*3*3) with three levels for all the three task-complexity dimensions (factors) is used for generating the number of runs necessary for the multiple linear regression analysis. The analysis of variance (ANOVA) model is used to accommodate the 3 levels of each task-complexity dimension and avoid the requirement that the 3 levels of any given task-complexity dimension be equally spaced. Analysis of variance (ANOVA) is also used to account variance in measurement scales and not to force linear relationship. All 27 scenarios (or data points) would be conducted two times to capture a better picture of how teams perform various task-complexity scenarios. As per the full factorial design all participant teams (2-member teams) would be randomly assigned to perform one particular run or task-complexity scenario. Thus the present experimental design needs a total of 54 two-member teams (108 participants).

Table 4.1 gives the 27 runs or task-complexity scenarios of the $3^3$ full factorial design. Task-performance values of all the 54 data points will be calculated. A multiple linear regression analysis would be conducted to see the variation of teams' task performance and to test all the five hypotheses. Table 4.2 explains the description of the complexity levels of each task-dimension (1 (low), 0 (medium) and 1 (high) levels) considered for the purpose of the present experimental study.

**Example:** A task scenario of low task-scope (-1) that requires medium coordination (0) with high uncertainty (1) is, T (-1, 0, 1) = Identifying 10 (hostile and friendly) planes requiring 20 ideal interactions (or chunks of information exchange flows) with 8 random (uncertain) events. Section 4.5.1.5 explains the task complexity metrics and quantification with a sample task scenario.

**Table 4.1 $3^3$ Full Factorial Designs**

| Run Number | Task - scope (S) | Task- coordination (C) | Task- uncertainty (U) | No of Repetitions | Team task- performance (Y) |
|---|---|---|---|---|---|
| 1 | -1 | -1 | -1 | 2 | |
| 2 | -1 | -1 | 0 | 2 | |
| 3 | -1 | -1 | 1 | 2 | |
| 4 | -1 | 0 | -1 | 2 | |
| 5 | -1 | 0 | 0 | 2 | |
| 6 | -1 | 0 | 1 | 2 | |
| 7 | -1 | 1 | -1 | 2 | |
| 8 | -1 | 1 | 0 | 2 | |
| 9 | -1 | 1 | 1 | 2 | |
| 10 | 0 | -1 | -1 | 2 | |
| 11 | 0 | -1 | 0 | 2 | |
| 12 | 0 | -1 | 1 | 2 | |
| 13 | 0 | 0 | -1 | 2 | |
| 14 | 0 | 0 | 0 | 2 | |
| 15 | 0 | 0 | 1 | 2 | |
| 16 | 0 | 1 | -1 | 2 | |
| 17 | 0 | 1 | 0 | 2 | |
| 18 | 0 | 1 | 1 | 2 | |
| 19 | 1 | -1 | -1 | 2 | |
| 20 | 1 | -1 | 0 | 2 | |
| 21 | 1 | -1 | 1 | 2 | |
| 22 | 1 | 0 | -1 | 2 | |
| 23 | 1 | 0 | 0 | 2 | |
| 24 | 1 | 0 | 1 | 2 | |
| 25 | 1 | 1 | -1 | 2 | |
| 26 | 1 | 1 | 0 | 2 | |
| 27 | 1 | 1 | 1 | 2 | |

**Note:** -1, 0 and 1 represent low, medium and high levels of the three dimensions (Factors)

**Table 4.2 Description of Task Complexity Levels of Each Task-Dimension**

| Complexity Level | Task Scope | | Task Coordination | Task Uncertainty |
|---|---|---|---|---|
| -1 (low) | 10 Objects to be identified (Hostile & Friendly) | 2 DCA 10 Other Objects | Ideal Interactions Necessary = 2 planes requiring coordination *5 information exchange flows=10 | No Random Events |
| 0 (Medium) | 20 Objects to be identified (Hostile & Friendly) | 4 DCA 10 Other Objects | Ideal Interactions Necessary = 4 planes requiring coordination *5 information exchange flows = 20 | 4 Random Events |
| 1(High) | 30 Objects to be identified (Hostile & Friendly) | 6 DCA 10 Other Objects | Ideal Interactions Necessary = 8 planes requiring coordination *5 information exchange flows = 40 | 8 Random Events |

All the events were generated as described in the Table 4.2. In all these scenarios, random events are the only form of task uncertainty.

**4.2 Participants**

One hundred and eight participants were recruited from undergraduate/graduate students at Louisiana State University on a volunteer basis who had the knowledge and experience of working as teams for academic class projects and computer simulation/video games. Participants were recruited using posters (See Appendix B) that indicated the need for participants for an experiment that focuses on teams and task-complexity. Participants recruited from classes were given extra bonus points by the faculty member in their respective classes for participating in the experiment.

All participants had an equivalent amount of computer experience and have normal or corrected to normal vision. A survey questionnaire was conducted before the experiment to ensure subjects have relatively the same level of experience. Participants were awarded the bonus credit irrespective of their eligibility to participate in the experiment. Each participant was asked to indicate his or her level of experience on group projects and computer simulation tasks to ensure all the participants have relatively the same level of experience. Participants work as teams of two people in performing the experimental task. Thus 54 teams were formed with two participants in each team. Participants were randomly picked to form a particular team.

### 4.3 Equipment and Material

The equipment and material needed to conduct the experimental task are as described in the Table 4.3. Each team, which has two members, has two roles to be performed. A 2-role Team Aegis Simulation Platform (TASP) simulation was used for these experiments. It requires 3-networked computers with one computer acting as server and two other computers, located in different rooms, used by each team member. The roles of team members were assigned on a random basis and were explained in a detailed manner by the experimenter. Section 4.5.1 provides more details of the TASP simulation, roles of the team members, Script Maker and Converter software.

### 4.4 Experimental Design Procedure

The experimental procedure was a two-stage procedure comprising the training stage and experimental stage. The participant team was subjected to meet a minimum amount of team performance in order to participate in the experimental stage. This was to make sure all that all the participant teams had sufficient knowledge in performing the experimental task and to avoid the possibility of inconsistency. The experimental procedure used is portrayed in Table 4.4. In the training stage, teams consisting of two participants first complete initial data forms (subject information and prior experience questionnaire, and experiment consent form).

Upon completion of these forms, teams were given the experimental task description and guidelines packet that consists of Rules of Engagement (ROEs) and other technical information to be remembered in order to perform TASP simulation tasks. During this stage, any of the participant team's questions were answered regarding the experimental simulation task. Upon completion of the experiment description and all questions answered, participant team participated in a 50-minute training session, comprising of two training tasks, to acclimate them to the TASP simulation environment. Each training task is 20 minutes in duration with a 10-minute break in between them.

**Table 4.3 Required Equipment and Material**

| Equipment Name | Specifications | Number of Equipment |
|---|---|---|
| Server Workstation | Memory RAM: 4 GB<br>Hard Drive Capacity: 136GB<br>Operating System: Windows 2000 Server Edition or above<br>Support Software: JAVA SDK 1.4.2<br>Processor: Dual Processor Intel Pentium (P4) 2.53 GHz | 1 |
| Work Stations | Processor: Intel P4 2.53 GHz<br>Memory RAM: 1 GB<br>Hard Drive Capacity: 80GB<br>Operating System: Windows XP<br>Support Software: JAVA SDK 1.4.2 | 2 |
| TASP Simulation | Team Aegis Simulation Platform (TASP) version 3.0 | 1 |
| ScriptMaker | A team task scenario development tool version 3.1 | 1 |
| Converter | A data converter into MS Access database | 1 |
| MS Access | A Microsoft Access database software | 1 |
| Other | Separate Experimental rooms or separated areas | 2 |
| Experiment Location | Collaboration, Human, and Machine Performance (CHaMP) Laboratory, 3413 CEBA Building, LSU | |

Participant teams were informed to come for second stage, experimental stage, provided they meet the minimum required team performance of identifying 50 percent of the given target objects. Experimental stage consists of a quick review and performing the actual experimental task scenario (30 mins) followed by post-experimental data collection (Perceived Task-Workload Survey or NASA TLX Form). Past studies by Rothrock (2001 and 2002) and colleagues observed lack of interest by the teams if duration of the team simulation games is more than 30 minutes. Thus, all the actual experimental scenarios are created for 30 minutes in duration.

**Table 4.4 Experimental Procedure**

| Experimental Stage | Time | Description |
|---|---|---|
| **Training Stage** | | Day 1- Duration = 70 minutes |
| Participant Data Collection | 10 mins | Participant Information and Prior Experience Questionnaire, Experiment Consent Forms. |
| Task Description and Guidelines | 15 mins | Task-description and guidelines packet will be given for reading and concerning questions will be answered. |
| Training Task 1 | 20 mins | TASP simulation training task 1 |
| Break | 10 mins | Ten-minute break period |
| Training Task 2 | 20 mins | TASP simulation training task 2 |
| **Experimental Stage** | | Day 2 – Duration = 50 minutes |
| Quick Review | 10 mins | Brief review of the experimental task and guidelines packet |
| Experimental Scenario | 30 mins | Randomly assigned scenario (out of 20 scenarios) would be performed by the team |
| Post-experimental data collection | 10 mins | Perceived Task-Workload Survey (NASA TLX form) – used for cross validation of the team task-performance |

### 4.4.1 Experimental Task

The present study used the 2-Role Team Aegis Simulation Platform (TASP) simulation where the team is organized into a command hierarchy of one team leader (AAWC) and one supporting team member. The 2-Role TASP Simulation requires 3-networked computers, one server computer and the remaining two computers were used by each team member. The overarching team responsibilities are protecting their own ship and other friendly assets in the battlegroup by monitoring the airspace, identifying unknown air contacts, and taking both defensive and offensive actions as prescribed by the Rules of Engagement (ROEs) (refer to Table 12). Description of rules of engagement (ROEs) would be provided during the training stage/experimental stage to all the team members. These ROEs are same for all the 27 experimental scenarios (runs). A detailed view of experimental set-up is shown in the Figure 4.1.

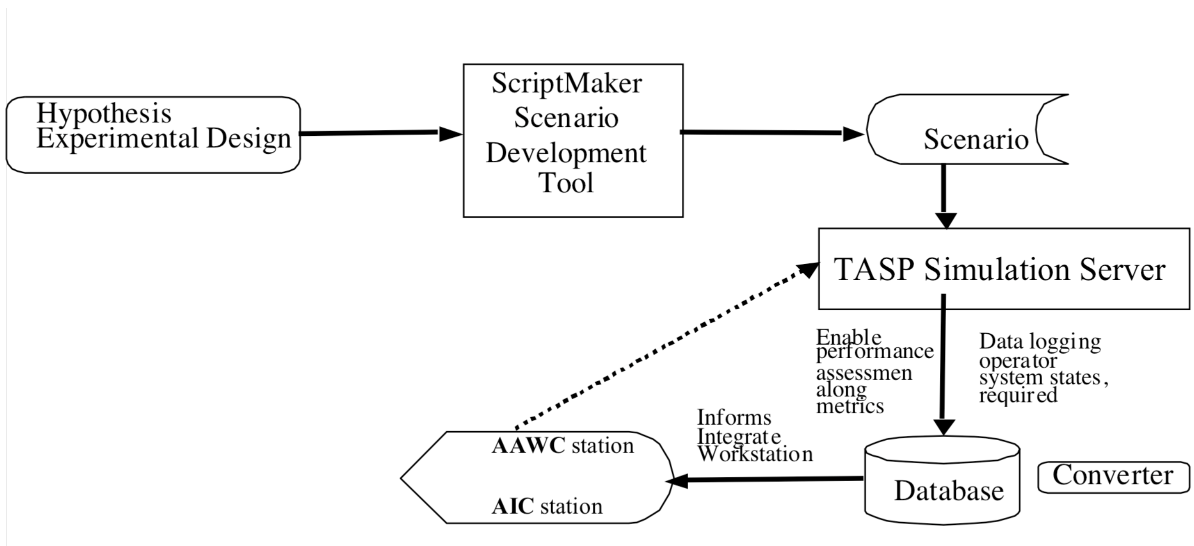



**Figure 4.1 Experimental Set-Up**

#### 4.4.1.1 Anti-Air Warfare Coordinator (AAWC)

The team leader, the Anti-Air Warfare Coordinator (AAWC), is responsible for monitoring a radar scope and identifying all air contacts that appear on the screen. The radar scope along with the air contacts are pictured on the right side of the interface displayed in Figure 4.2. To make identifications, the AAWC may use a variety of information about the unknown air contacts displayed in the Character Readout (CRO) located in the upper left-hand corner of the screen. Examples of this information include altitude, speed, range from their own ship, point of origin, and direction of travel. The AAWC uses either the keyboard or a mouse to interact with the menu displayed across the bottom of the interface. The AAWC coordinates with the supporting team member, Air Intercept Coordinator (AIC), to obtain additional information prior to making identifications. Table 4.5 shows the primary tasks of Anti-Air Warfare Coordinator (AAWC) and Table 4.6 shows the TASP simulation rules of engagement.

#### 4.4.1.2 Air Intercept Coordinator (AIC)

The Air Intercept Coordinator (AIC) is responsible for monitoring, managing, and protecting friendly air assets called Defensive Counter Aircraft (DCA). DCA may be ordered by the AIC to vector to an unidentified air contact and make a definitive visual identification (VID). The control of DCA is accomplished using the panel under the CRO in Figure 4.3. Table 4.5 shows the primary tasks of Air Intercept Coordinator (AIC) and Table 4.6 shows the TASP simulation rules of engagement.

**Table 4.5 Primary Tasks: AAWC and AIC**

| **AAWC** (Primary Tasks) | **AIC** (Primary Tasks) |
|---|---|
| Enter track designation | Engage track from DCA |
| Enter track primary identification | Illuminate track from DCA |
| Engage track from own ship | Vector DCA to obtain track VID |
| Illuminate track from own ship | Vector DCA to refuel |
| Requisition replacement DCA | Vector DCA to range within 256 NM |
| | Vector DCA to range outside of 20 NM |
| | Vector DCA outside of danger zone |

The DCA information panel that provides updates on all DCA launched.

The new CRO - These values are synchronized on all two workstations.

The Selected Track is in Blue

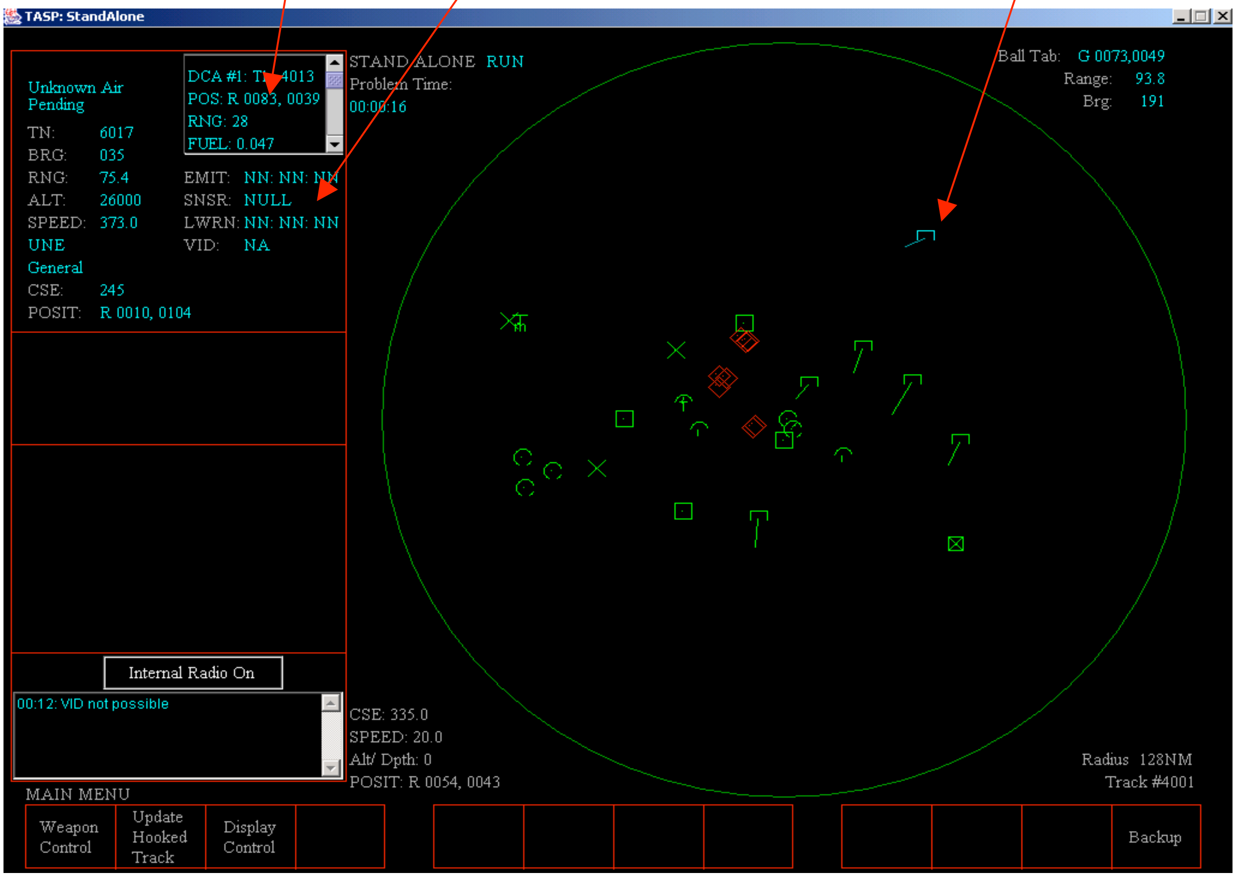
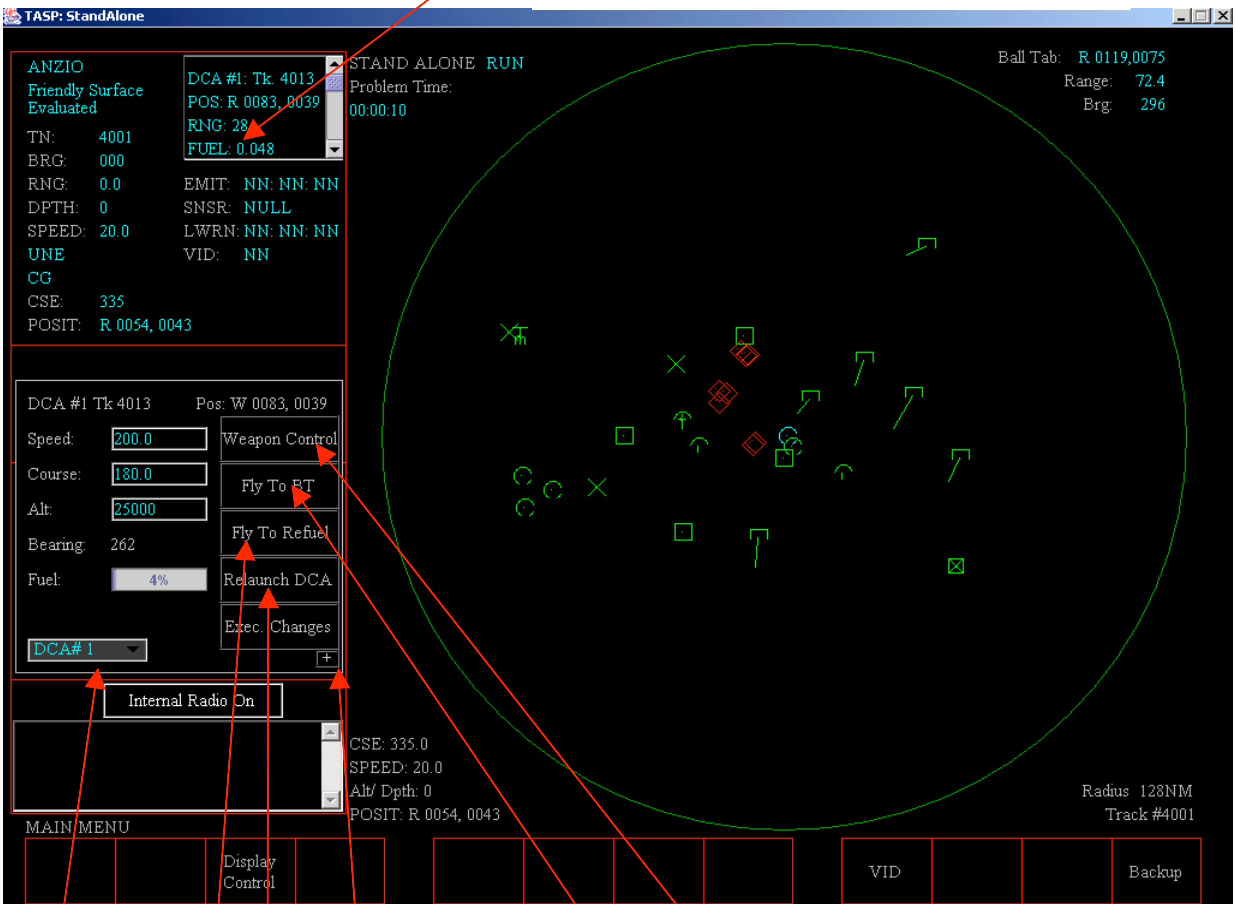



**Figure 4.2 AAWC Interface**

To change DCA parameters

1. Select DCA from the drop down box
2. Edit/ Change Speed, Course, or Alt to specified value
3. Click "Exec Changes"




Available DCA can be selected from this drop down box

Click this button for the keyboard focus to transfer to "Fly to BT" button.

Click this button, to view the menu for weapon control available on the selected DCA in the drop down box.

DCA can be launched only when one has been downed.

To fly the Refuel Point

1. Select the refuel Tanker on the radar scope.
2. Select the DCA from the drop down box on the DCA Panel
3. Click on the "Fly To Refuel" button to fly the DCA to refuel point.

Now the DCA will course towards the Refuel point (tanker).

To fly the DCA to BT

1. Select the DCA from the drop down box on the DCA Panel
2. Click on the "+" button so that the key focus transfers to "Fly to BT" button.
3. Position the mouse anywhere in the radar ring.
4. Press **"Space"** key

Now the DCA will course towards the BT

**Figure 4.3 AIC Interface**

**Table 4.6 TASP Simulation Rules of Engagement (ROEs)**

| TASP Rule Number | Description of Rules of Engagement (ROEs) |
|---|---|
| 1 | All hostile air platforms within the range of 20 NM must be engaged |
| 2 | All hostile air platforms within the range of 30 NM must be illuminated |
| 3 | All hostile air platforms must be issued a level 1 warning between the ranges of 50 and 40 NM (given once) |
| 4 | All hostile air platforms must be issued a level 2 warning between the ranges of 40 and 30 NM (given once) |
| 5 | All hostile air platforms must be issued a level 3 warning between the ranges of 30 and 20 NM (given once) |
| 6 | DCAs are restricted to fly between 20 and 256 NM |
| 7 | All unknown tracks (i.e., hostile & neutral platforms) must be assigned correct primary identifications |
| 8 | All unknown tracks (i.e., hostile & neutral platforms) must be assigned correct designations |
| 9 | AIC must follow all lawful AAWC orders (i.e., consistent with Rules 1-8) |
| 10 | Maintain DCA's by taking preventive measures such as timely refuel, avoiding danger zone and being engaged. |

#### 4.4.1.3 Script Maker

The scenario generation tool, called Script Maker (Rothrock, 2002) provides the context for the simulation through the construction of scenario events that are bounded by temporal, kinematic, and knowledge-based constraints (Builder, 1983; Pace, 1986; Cannon-Bowers, Burns, Salas, and Pruitt, 1998; Maule, Hockey, and Bdzola, 2000). The present study uses the Script Maker tool to create a set of scenarios that require extensive use of teamwork skills. For example, incorporating a large number of events that are likely to overwhelm one of the team members creates a situation that requires the teamwork skill of backing up your teammate.

Similarly, designing a scenario in which the context dramatically changes (perhaps from routine to threatening) requires the use of effective leadership and communication to help the team maintain a common situational awareness.

#### 4.4.1.4 Converter

TASP Simulation collects the data of both the AAWC and AIC operators every 6 seconds and stores them as the text files. These text files later can be converted into MS Access database using the Converter software. The required information for the present research could be further synthesized to calculate the team performance for that particular scenario (one of the 27 runs of the $3^3$ full factorial design as shown in the Table 4.7).

#### 4.4.1.5 Task-Complexity Metrics and Quantification

Task-complexity score is calculated by means of the chunks of information as the metrics. An example scenario will be explained for better understanding.

**Example Scenario [Task (-1, 0, 1)]:** A task scenario of low task scope (-1) that requires medium coordination (0) with high uncertainty (1) is,

T (-1, 0, 1) = Identifying 10 Objects (Hostile & Friendly) to be identified with 4 objects requiring coordination with 5 ideal interactions per object while encountering 8 random (or unexpected) events.

**1. Task-Scope**

Number of sub-tasks or objectives, O = 10 unidentified planes (chunks of information)

Amount of information processed, I = (total number of planes) * (number of parameters processed per plane + number of rules of engagement) = (TP) * (P + ROEs)

Amount of information, I = (20) * (6 + 10) = 320 (chunks of information)

Total number of planes used in the scenario, TP = 20 (chunks of information)

Number of parameters processed per plane, P = 6 (such as range, track number, VID number, IFF code, altitude and speed)

Total task-scope (S) = number of sub-tasks (O) + amount of information (I) (3)

Total task-scope, S= 10 + 320 = 330 (chunks of information)

**2. Task-Coordination**

Number of interactions needed to achieve an objective = 5 (chunks of information flow)

Each Interaction ideally requires: AAWC requests VID from AIC + AIC requests track information from AAWC+ AAWC sends Track information to AIC + AIC sends VID information to AAWC+ AAWC confirms VID

Total task-coordination I = Number of objectives that require an coordination * 5

Total task-coordination I = 4*5 =20 (chunks of information flow)

**3. Task-Uncertainty**

Internal Confidence = Amount of Uncertainty = 0

External Constraints = No External Constraints = 0

Random Events = Number of Unexpected Events = 8 unexpected planes (chunks of information)

Total Uncertainty (U) = 8 (chunks of information of unexpected planes)

#### 4.4.1.6. Team Performance

The performance measurement approach is centered on a measurement construct called time windows (Rothrock, 2001). A time window is essentially an opportunity for an action to be taken. Each action required by a time window has a specified initial condition at which it becomes appropriate and a specified close condition, before which it must be performed. This interval is the time window associated with the action. Outcomes can be classified into the six categories explained in Figure 2.4 (refer to section 2.7.1). These categories form the basis on which TASP measures performance of experimental participants. To illustrate, consider that an unknown track has appeared on the radar. This event opens a time window for the action – "identify track". This time window closes when the opportunity no longer exists, in this case, whenever the track disappears from the radar. Once this time window closes, any action is considered late. If an action was taken, then it fits into one of the four categories of correct action shown in Figure 2.4 (refer to section 2.7.1). If no action is taken, it's a miss, and if an action is taken without an opportunity, it's a false alarm.

In the recent discussions with, Rothrock (2005), early correct and late correct actions can be considered as false alarms since they do not practically exist. Thus early correct (2) and late correct (3) should be categorized and placed with false alarms (5). Figure 2.5 (refer to section 2.7.1) shows a modified version of the possible time window outcomes. In TASP, a complete list of time windows is generated by listing all possible opportunities available to a specified role. TASP simulation uses blackboard agents to continuously monitor each workstation for conditions to open and close time windows.

Another distinctive feature of TASP is its ability to measure team performance metrics such as information exchange, communications, and supportive behavior (backup and error correction). Based on the nature of the corresponding role, each time window is categorized as primary, backup or error correction. Primary time windows relate to tasks that a team member performs to meet responsibilities characterizing his role. Backup time windows are those that relate to tasks in which a team member assists another team member in achieving his primary responsibilities. Error correction time windows provide team members with an opportunity to rectify an inaccurately performed task.

The simulation has data logging capabilities that record an operator's resource management and problem solving skills. Seven output files are generated during each session of experimentation. During the simulation, the simulation explicitly logs opening and closing times of each time window, responses by team members and evolving state of the environment. These output files record detailed information, such as mouse clicks and keyboard presses, along with time stamps and the state of the environment at which it was executed. These data files provide valuable resources for conducting a wide range of performance analyses on the team and its participants. Based on the training objective, the investigator has the capability to consolidate and associate different sources of data elements.

Team performance would be determined based on the number of objectives correctly identified (on-time). Number of objectives that are identified correctly (early and/or late) are considered as false alarms (Rothrock, 2005). The percentage of correctly identified objectives (on-time) will be the measure of team performance.

**4.5 Hypothesis Analysis**

A multiple linear regression analysis was performed to capture and view the over all contribution of each dimension towards complexity and performance. Instead of using partial regression analysis to test each hypothesis, effect tests and analysis of higher order interactions from the full multiple linear regression analysis were used for robustness and maximum error degrees of freedom.

**4.5.1 Hypothesis 1**

Task-scope, task-coordination, and task-uncertainty, as dimensions of task complexity, do not contribute in equal proportion to the team task-performance.

Dependent Variable : team task-performance

Independent Variable : task-scope, task-coordination, task uncertainty

Scenarios (runs) data from Table 4.7 (refer to section 4.1) were used to evaluate and test hypothesis 1. A multiple linear regression analysis was performed to evaluate and test the hypothesis 1 and to know the over all contribution of the three proposed task dimensions (task-scope, task-coordination and task-uncertainty) towards task-complexity and task-performance. Hypothesis 1 also validates whether the three task complexity dimensions were equally contributing towards team task-complexity and task-performance or not. This is a full model analysis and evaluates all the three main affects (scope, coordination and uncertainty) and interactions with the maximum degrees of freedom. Detailed explanation of the effect tests and full model analysis of task-scope, task-coordination and task-uncertainty effect on task performance was presented in the results section.

**4.5.2 Hypothesis 2**

Task-scope and task-coordination, as dimensions of task complexity, do not contribute in equal proportion to the team task-performance.

Fixed Variables : task-uncertainty (=0)

Dependent Variable : team task-performance

Independent Variable : task-scope, task-coordination

The objective of hypothesis 2 was to evaluate whether the task-scope and task-coordination are contributing equally towards the team task-performance or not when uncertainty is negligible. In other words it is the full model to know the over all contribution of the task-scope and task-coordination dimensions towards task-complexity and task-performance when task-uncertainty negligible or zero. Though partial regression analysis option could be considered, it has less number of degrees of freedom to validate the task-scope and task-coordination when uncertainty is negligible or zero. Effect tests from the full multiple linear regression analysis evaluate all the main affects and interactions with the maximum degrees of freedom. Thus, there is no need to specially use contrasts or partial multiple linear regression analysis to test the hypothesis 2.

In order to evaluate the hypothesis 2 and to understand the significance of task-scope and task-coordination, multiple linear regression was performed with task-uncertainty constant at low level (-1). Hypothesis 2 shows whether the task-scope and task-coordination are contributing equally towards the team task-performance or not. Detailed explanation of the effect tests and analysis of task-scope and task-coordination effect on task performance was presented in the results section.

**4.5.3 Hypothesis 3**

Difference in team task performance exists as task complexity is increased by the task-scope (number of sub-tasks and the amount of information-processed).

Dependent Variable : team task-performance

Independent Variable : task scope

The objective of hypothesis 3 was to evaluate whether the task-scope is affecting the team task-performance significantly as a task-dimension or not. Though partial regression analysis option could be considered, it has less number of degrees of freedom to validate the task-scope and also not robust. Effects tests from the full multiple linear regression analysis evaluate all the main affects and interactions with maximum degrees of freedom. Thus there is no need to specially use contrasts or partial regression analysis to test the hypothesis 3 on task-scope. Detailed explanation of the effect tests and analysis of task-scope's effect on task performance was presented in the results section.

### 4.5.4 Hypothesis 4

Difference in team task performance exists as task complexity is increased by the task-coordination (number of coordination information flows and interactions).

Dependent Variable : team task-performance

Independent Variable : task-coordination

The objective of hypothesis 4 was to evaluate whether the task-coordination is affecting the team task-performance significantly as a task-dimension or not. Though partial regression analysis option could be considered, it has less number of degrees of freedom to validate the task-coordination and also not robust. Effects tests from the full multiple linear regression analysis evaluate all the main affects and interactions with the maximum degrees of freedom. Thus there is no need to specially use contrasts or partial regression analysis to test the hypothesis 4. Detailed explanation of the effect tests and analysis of task-coordination's effect on task performance was presented in the results section.

### 4.5.5 Hypothesis 5

Difference in team task performance exists as task complexity is increased by the task-uncertainty (number of internal, external uncertainty and random events).

Dependent Variable : team task-performance

Independent Variable : task uncertainty

The objective of hypothesis 5 was to evaluate whether the task-uncertainty is affecting the team task-performance significantly as a task-dimension or not. Though partial regression analysis option could be considered, it has less number of degrees of freedom to validate the task-scope and also not robust. Effects tests from the full multiple linear regression analysis evaluate all the main affects and interactions with maximum degrees of freedom. Thus there is no need to specially use contrasts or partial regression analysis to test the hypothesis 5. Detailed explanation of the effect tests and analysis of task-uncertainty's effect on task performance was presented in the results section.

# CHAPTER 5

# RESULTS AND DISCUSSION

The analysis of the data collected in the experiments is presented in this section. The results associated with the analysis of each hypothesis are considered and discussions are presented to investigate the effect of task-scope, task-coordination and task-uncertainty dimensions of the team task complexity space on team performance.

## 5.1 Experimental Results

A full $3^3$ factorial design was used during the experiment. A total of 54 teams completed 27 experimental scenarios (e.g., 2 teams per scenario). Summary of the task performance data was depicted in the Table 5.1. It gives average task performance and standard deviation for each of the 27 experimental scenarios. From Table 5.1, the average task-performance for all the teams regardless of condition was 0.7114 (out of maximum possible 1.0) or 71.14 percent and the total average standard deviation was 0.0581. Here the performance scale is based on the percentage of number of successful tasks accomplished on time during the team simulation scenarios. For some of the scenarios with combination of lower levels of scope with either coordination or uncertainty, the performance of the two different teams was the same. Thus this explains why some standard deviations are zero. A detailed explanation of the statistical analysis would be presented in the following sub-sections. First, a full model analysis would be discussed before discussing the individual hypothesis analysis.

### 5.1.1 Hypothesis 1: Full Model Analysis

Task scope, task-coordination, and task-uncertainty, as dimensions of task complexity, do not contribute in equal proportion to the team task-performance.

Dependent Variable : team task-performance

Independent Variable : task-scope, task-coordination, task-uncertainty

**Table 5.1 Summary of Team Performance Data**

| Run Number | Task scope | Task co-ordination | Task un-certainty | Team Task performance | |
|---|---|---|---|---|---|
| | | | | Avg. Performance | Standard Deviation |
| 1 | -1 | -1 | -1 | 1 | 0 |
| 2 | -1 | -1 | 0 | 0.8 | 0 |
| 3 | -1 | -1 | 1 | 0.75 | 0.071 |
| 4 | -1 | 0 | -1 | 0.8 | 0 |
| 5 | -1 | 0 | 0 | 0.5 | 0 |
| 6 | -1 | 0 | 1 | 0.7 | 0 |
| 7 | -1 | 1 | -1 | 0.75 | 0.071 |
| 8 | -1 | 1 | 0 | 0.5 | 0 |
| 9 | -1 | 1 | 1 | 0.4 | 0.141 |
| 10 | 0 | -1 | -1 | 0.925 | 0.035 |
| 11 | 0 | -1 | 0 | 0.7 | 0.071 |
| 12 | 0 | -1 | 1 | 0.825 | 0.106 |
| 13 | 0 | 0 | -1 | 0.7 | 0 |
| 14 | 0 | 0 | 0 | 0.825 | 0.106 |
| 15 | 0 | 0 | 1 | 0.675 | 0.035 |
| 16 | 0 | 1 | -1 | 0.775 | 0.106 |
| 17 | 0 | 1 | 0 | 0.65 | 0.141 |
| 18 | 0 | 1 | 1 | 0.65 | 0.141 |
| 19 | 1 | -1 | -1 | 0.933 | 0 |
| 20 | 1 | -1 | 0 | 0.783 | 0.024 |
| 21 | 1 | -1 | 1 | 0.7 | 0.047 |
| 22 | 1 | 0 | -1 | 0.883 | 0.024 |
| 23 | 1 | 0 | 0 | 0.533 | 0.094 |
| 24 | 1 | 0 | 1 | 0.7 | 0.047 |
| 25 | 1 | 1 | -1 | 0.767 | 0.047 |
| 26 | 1 | 1 | 0 | 0.45 | 0.165 |
| 27 | 1 | 1 | 1 | 0.533 | 0.094 |
| Overall Average Team Task Performance = | | | | | **0.7114** |
| Overall Standard Deviation of Team Task Performance = | | | | | **0.0581** |
| Number of Experiments = | | | | | **27** |
| Number of Repetitions = | | | | | **2** |
| Total Number of Experiments/Teams = | | | | | **54** |

Full model with repeated runs or scenarios gave team performance data of 54 teams and provided great scope for validating the influence of various levels of the proposed task-complexity dimensions on task performance. A multiple linear regression analysis was performed to validate whether all the three task-complexity dimensions conform to a linear fit with respect to team performance. The Analysis of Variance (ANOVA) model is used to accommodate the 3 levels of each task-complexity dimension and avoid the requirement that the 3 levels of any given task-complexity dimension be equally spaced. Analysis of Variance (ANOVA) is also used to account variance in measurement scales and not to force linear relationship. Multiple linear regression analysis of the full model shows that R-square fit is 0.878, which confirms that the model accounts for 88% of the variability in team performance (See Figure 5.1 and Table 5.2). Though participant teams were given proper training and checked for same level of prior experience, there always exists some variability between participant team members and also among the participant teams. Similarly the experimental testing equipment and measurements have some variability. Therefore, the remaining 12% of the model could be attributed to variability associated with experimental testing equipment, measurements and participants. There might also be potential other variables contributing to the remaining 12% of the model. But accounting 88% of variability in the team performance is a very good amount and strong enough to support the validity of this model. Analysis of variance (See Table 5.3) also strongly supports that the model was significant ($p < 0.0001$). Therefore, the model was strong and significant.

Results from the effects tests of the full model were depicted in the Table 5.4. The three-way interaction of scope, coordination, and uncertainty was significant ($p=0.019$). In addition, the two-way interaction between scope and uncertainty was found to be significant ($p= 0.0282$).

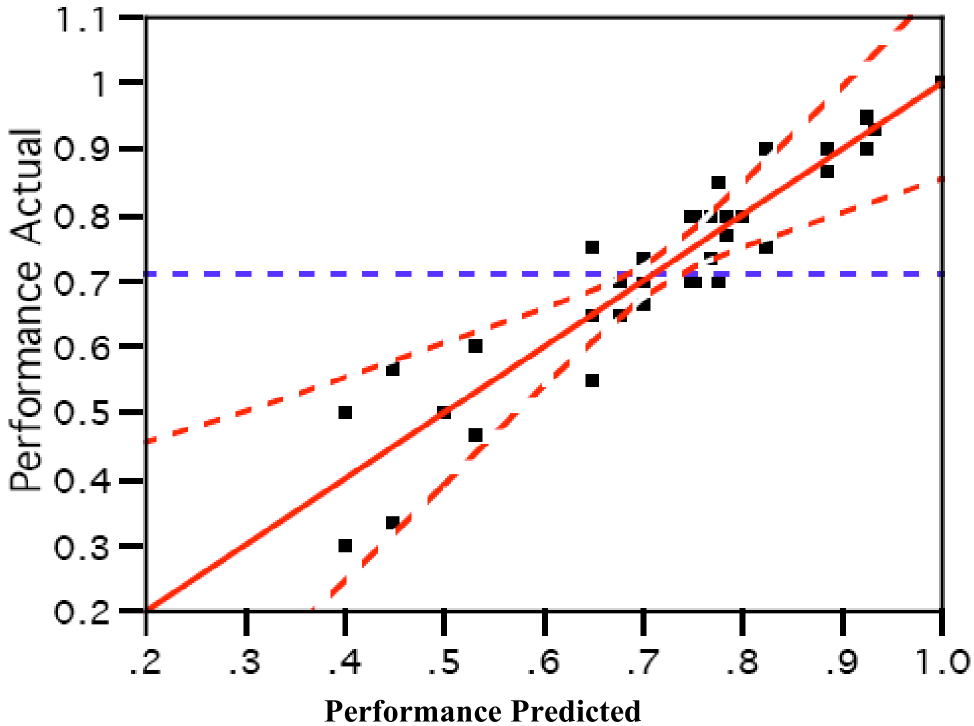



**Figure 5.1 Actual Vs Predicted Performance Plot**

**Table 5.2 Summary of Fit**

| | |
|---|---|
| **R-Square** | **0.8783** |
| **Root Mean Square Error** | 0.07794 |
| **Mean of Performance** | **0.7114** |
| **Number of Observations** | 54 |

The main effects, task-coordination and task-uncertainty were also found to be highly significant ($p < 0.0001$). Task-scope was not significant from the effects tests. A detailed analysis of 3-way interaction will reveal the exact reason. Though task-scope was not significant, it had significant interaction with the task-uncertainty. Significant 3-way interaction of the main effects and 2-way interaction of task-scope and task-uncertainty indicate that they have non-zero regression coefficients. As a result, regression coefficients of the main effects (scope, coordination and uncertainty) cannot have equal weight. In other words, hypothesis 1 informs that all the three dimensions were not equally contributing to the team task-complexity and task-performance.

**Table 5.3 Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| **Model** | 26 | 1.184 | 0.0455 | 7.50 | **0.0001** |
| **Error** | 27 | 0.164 | 0.006 | | |
| **Corrected Total** | 53 | 1.348 | | | |

**Table 5.4 Effect Tests**

| Source | DF | SS | Mean Square | F Value | Pr > F | |
|---|---|---|---|---|---|---|
| **Scope** | 2 | 0.035 | 0.018 | 2.91 | 0.0716 | Not Significant |
| **Coordination** | 2 | 0.421 | 0.211 | 34.68 | <0.0001 | **Significant** |
| **Scope*Coordination** | 4 | 0.05 | 0.013 | 2.07 | 0.1125 | Not Significant |
| **Uncertainty** | 2 | 0.43 | 0.215 | 35.40 | <0.0001 | **Significant** |
| **Scope*Uncertainty** | 4 | 0.078 | 0.020 | 3.20 | 0.0282 | **Significant** |
| **Coordination*Uncertainty** | 4 | 0.03 | 0.007 | 1.22 | 0.3254 | Not Significant |
| **Scope*Coordination*Uncertainty** | 8 | 0.14 | 0.017 | 2.87 | 0.0190 | **Significant** |

### 5.1.2 Analysis of 3-Way Interaction

Results from the effect tests indicate that task-coordination and task-uncertainty were very significant. However, another main affect, task-scope was not significant. But 3-way interaction of the main effects was significant, so a thorough analysis of 3-way interaction was needed. Roles of task-scope, task-coordination and task-uncertainty were evaluated and studied to know their importance at various levels.

**Task-Scope Role in 3-Way Interaction:** Since task-coordination and task-uncertainty were strongly significant and their 2-way interaction was not significant, first task-scope's role was evaluated in this 3-way interaction analysis. Thus, it is very useful to understand how the task-scope played a role in 3-way interaction and affecting the team performance at various levels of complexity. The 3-way interaction is sliced by 2-way interaction between task-coordination and task-uncertainty to understand the role of task-scope. Results from this 3-way interaction analysis were depicted in the Table 5.5. Results indicate that task-scope was playing significant role in the following combinations of task-coordination and task-uncertainty levels

- When task-coordination at medium (0) level and task-uncertainty medium (0) level
- When task-coordination at high (1) level and task-uncertainty medium (0) level
- When task-coordination at high (1) level and task-uncertainty high (1) level

Though task-scope came out not very significant, the three-way interaction analysis shows that it is in fact playing a significant role to some extent.

**Task-Coordination Role in 3-Way Interaction:** It is also very useful to understand how the task-coordination played a role in 3-way interaction and affecting the team performance at various levels of complexity. The 3-way interaction is sliced by 2-way interaction between task-scope and task-uncertainty to understand the role of task-coordination.

**Table 5.5 Task-Scope Role in 3-Way Interaction**

| Scope*Coordination*Uncertainty Effect Sliced by Coordination*Uncertainty for Performance | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Coordination** | **Uncertainty** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** | |
| -1 | -1 | 2 | 0.007 | 0.003380 | 0.56 | 0.5798 | Not Significant |
| -1 | 0 | 2 | 0.0115 | 0.005741 | 0.94 | 0.4012 | Not Significant |
| -1 | 1 | 2 | 0.016 | 0.007917 | 1.30 | 0.2882 | Not Significant |
| 0 | -1 | 2 | 0.034 | 0.016852 | 2.77 | 0.0802 | Not Significant |
| 0 | 0 | 2 | 0.128 | 0.063935 | 10.52 | 0.0004 | **Significant** |
| 0 | 1 | 2 | 0.0008 | 0.000417 | 0.07 | 0.9339 | Not Significant |
| 1 | -1 | 2 | 0.0007 | 0.000324 | 0.05 | 0.9482 | Not Significant |
| 1 | 0 | 2 | 0.043 | 0.021667 | 3.57 | 0.0422 | **Significant** |
| 1 | 1 | 2 | 0.063 | 0.031296 | 5.15 | 0.0127 | **Significant** |

Results from this 3-way interaction analysis were depicted in the Table 5.6. Results indicate that task-coordination was playing significant role in the following combinations of task-scope and task-uncertainty levels,

- When task-scope at low (-1) level and task-uncertainty low (-1) level
- When task-scope at low (-1) level and task-uncertainty medium (0) level
- When task-scope at low (-1) level and task-uncertainty high (1) level
- When task-scope at medium (0) level and task-uncertainty low (-1) level
- When task-scope at high (1) level and task-uncertainty medium (0) level

Though task-coordination came out very significant in the effect tests, the 3-way interaction analysis shows that it is better than task-scope and contributing significantly in the 3-way interaction.

**Table 5.6 Task-Coordination Role in 3-Way Interaction**

| Scope*Coordination*Uncertainty Effect Sliced by Scope*Coordination for Performance | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scope** | **Coordination** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** | |
| Low (-1) | Low (-1) | 2 | 0.07 | 0.035 | 5.76 | **0.0082** | **Significant** |
| Low (-1) | Medium (0) | 2 | 0.12 | 0.06 | 9.88 | **0.0006** | **Significant** |
| Low (-1) | High (1) | 2 | 0.143 | 0.072 | 11.80 | **0.0002** | **Significant** |
| Medium (0) | Low (-1) | 2 | 0.053 | 0.026 | 4.32 | **0.0235** | **Significant** |
| Medium (0) | Medium (0) | 2 | 0.033 | 0.016 | 2.67 | 0.0871 | Not Significant |
| Medium (0) | High (1) | 2 | 0.036 | 0.018 | 2.95 | 0.0694 | Not Significant |
| High (1) | Low (-1) | 2 | 0.03 | 0.015 | 2.41 | 0.1091 | Not Significant |
| High (1) | Medium (0) | 2 | 0.12 | 0.06 | 9.91 | **0.0006** | **Significant** |
| High (1) | High (1) | 2 | 0.037 | 0.019 | 3.05 | 0.0640 | Not Significant |

**Task-Uncertainty Role in 3-Way Interaction:** It is also very useful to understand how the task-uncertainty played a role in 3-way interaction and affecting the team performance at various levels of complexity. The 3-way interaction is sliced by 2-way interaction between task-scope and task-coordination to understand the role of task-uncertainty. Results from this 3-way interaction analysis were depicted in the Table 5.7. Results indicate that the task-uncertainty was playing highly significant role in almost all combinations of task-scope and task-coordination levels.

The following are the combinations, where it was not significant,

- When task-scope at medium (0) level and task-coordination medium (0) level
- When task-scope at medium (0) level and task-coordination high (1) level

Task-uncertainty is highly significant from the effect tests. Now, the 3-way interaction analysis also shows that, task-uncertainty is playing a significant role better than task-scope and task-coordination as well as contributing to the maximum extent in the 3-way interaction.

**Table 5.7 Task-Uncertainty Role in 3-Way Interaction**

| Scope*Coordination*Uncertainty Effect Sliced by Scope*Coordination for Performance | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scope** | **Coordination** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** | |
| Low (-1) | Low (-1) | 2 | 0.070 | 0.035 | 5.76 | **0.0082** | **Significant** |
| Low (-1) | Medium (0) | 2 | 0.093 | 0.047 | 7.68 | **0.0023** | **Significant** |
| Low (-1) | High (1) | 2 | 0.130 | 0.065 | 10.70 | **0.0004** | **Significant** |
| Medium (0) | Low (-1) | 2 | 0.051 | 0.025 | 4.18 | **0.0261** | **Significant** |
| Medium (0) | Medium (0) | 2 | 0.026 | 0.013 | 2.13 | 0.1388 | Not Significant |
| Medium (0) | High (1) | 2 | 0.021 | 0.01 | 1.71 | 0.1991 | Not Significant |
| High (1) | Low (-1) | 2 | 0.056 | 0.028 | 4.60 | **0.0191** | **Significant** |
| High (1) | Medium (0) | 2 | 0.123 | 0.06 | 10.09 | **0.0005** | **Significant** |
| High (1) | High (1) | 2 | 0.11 | 0.054 | 8.87 | **0.0011** | **Significant** |

Summary of 3-way interaction analysis,

- The results indicate that task-scope was playing significant role in the 3-way interaction only when task-coordination and task-uncertainty both are at levels (0, 0) or (1, 0) or (1, 1). Therefore, task-scope is significant only in three higher complexity conditions.
- Task-scope was not playing significant role in the 3-way interaction and towards task-complexity and team performance.

Thus from the analysis of 3-way interaction, it is evident that task-scope as a dimension playing a significant role at only few higher complexity levels of coordination and uncertainty. Though the present study and experimental results won't strongly support validity of task-scope as a particular dimension, there is reasonable support of its significance at higher complexity levels.

### 5.1.3 Hypothesis 2

Task-scope and task-coordination as dimensions of task complexity will not contribute in equal proportion to the effect on team performance.

Fixed Variables : task-uncertainty (=0)

Dependent Variable : team task-performance

Independent Variable : task scope, task-coordination

The objective of hypothesis 2 was to evaluate whether the task-scope and task-coordination are contributing equally towards the team task-performance or not when task-uncertainty is negligible or zero. Though partial regression analysis option was considered earlier, it did not provide enough degrees of freedom to validate the task-scope and task-coordination when task-uncertainty is negligible or zero. But effects tests from the full multiple linear regression analysis evaluate all the main affects and interactions with maximum degrees of freedom. In order to evaluate the hypothesis 2, the 3-way interaction is sliced by main effect task-uncertainty to understand the significance of task-scope and task-coordination when task-uncertainty is negligible or zero.

Results from this 3-way interaction analysis were depicted in the Table 5.8. Detailed explanation and analysis of the task-scope and task-coordination affect on task-performance were presented below.

Results from the effect tests (Refer, Table 5.4) indicate that the 2-way interaction of task-scope and task-coordination was not significant. But results from the analysis of 3-way interaction sliced by main effect task-uncertainty, show that 2-way interaction of task-scope and task-coordination is significant ($p < 0.0081$) when task-uncertainty was negligible or zero (at -1 level). Significant 2-way interaction of task-scope and task-coordination indicates that both are significant task-complexity dimensions when uncertainty is zero. 2-way interaction of task-scope and task-coordination also indicate that it has non-zero regression coefficient. As a result, regression coefficients of the task-scope and task-coordination cannot have equal weight. In other words, hypothesis 2 informs that the two dimensions, scope and coordination, were not equally contributing to the team task-complexity and task-performance.

**Table 5.8 Analysis of Hypothesis 2**

| **Scope*Coordination*Uncertainty Effect Sliced by Uncertainty for Performance** | | | | | |
|---|---|---|---|---|---|
| **Uncertainty** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
| **-1** | 8 | 0.164475 | 0.020559 | 3.38 | **0.0081** |
| **0** | 8 | 0.341420 | 0.042677 | 7.02 | <0.0001 |
| **1** | 8 | 0.248179 | 0.031022 | 5.11 | 0.0006 |

### 5.1.4 Hypothesis 3

Differences in team task performance exist as task complexity is increased by the task-scope (number of sub-tasks and the amount of information-processed).

Dependent Variable : team task-performance

Independent Variable : task scope

The objective of hypothesis 3 was to evaluate whether the task-scope is affecting the team task-performance significantly as a task-dimension or not. Though partial regression analysis option was considered earlier, it did not provide enough degrees of freedom to validate the task-scope and also, it is not robust. Effects tests from the full multiple linear regression analysis evaluate all the main affects and interactions with the maximum degrees of freedom. Therefore, there was no need to specially use contrasts or partial regression analysis to test the hypothesis 3.

Results from effect tests indicate that the task-scope is not significant (p=0.0716). Table 5.9 summarizes the hypothesis 3 results from effect tests. Least square means plot of the task-scope Vs task-performance is shown in the Figure 5.2. Table 5.10 shows that there was not much a difference in the task performance mean among the three task-scope complexity levels. Least square means plot also indicates the same.

**Table 5.9 Effect Tests: Hypothesis 3**

| Source | DF | F Value | Pr > F | |
|---|---|---|---|---|
| **Scope** | 2 | 2.91 | 0.0716 | Not Significant |
| **Scope*Coordination*Uncertainty** | 8 | 2.87 | **0.0190** | **Significant** |

**Table 5.10 Task-Scope: Least Square Means**

| Level | Standard Error | Least Square Means: Task Performance |
|---|---|---|
| -1 | 0.0181 | 0.689 |
| 0 | 0.0181 | 0.742 |
| 1 | 0.0181 | 0.698 |

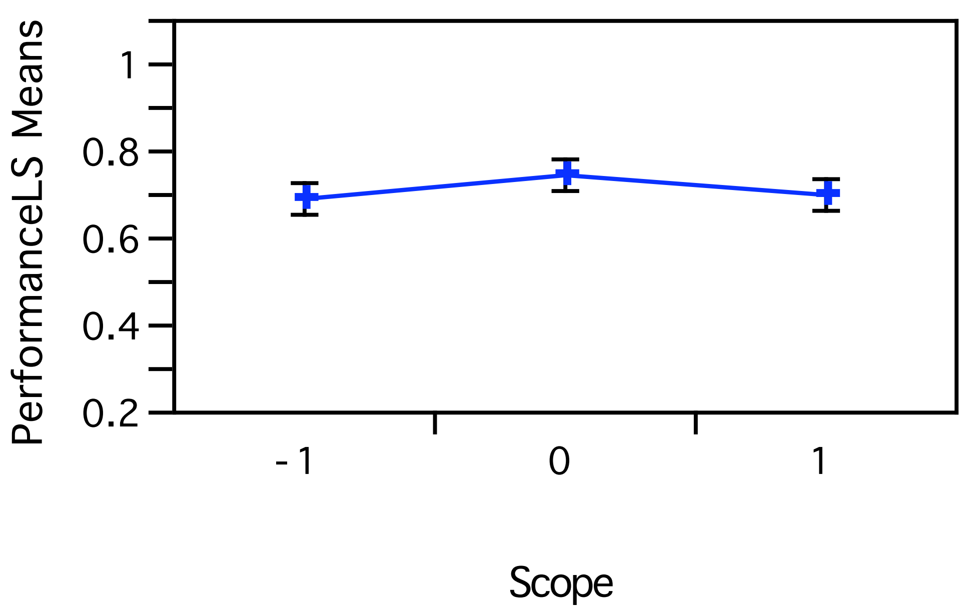



**Figure 5.2 Task-Scope Vs Performance Least Square Means Plot**

Though task-scope came out insignificant from the effect tests, it was significant in hypothesis 2 and it also had affect on performance at higher levels of task-coordination and task-uncertainty as noted in the previous 3-way interaction analysis. Therefore, hypothesis 2 together with 3-way interaction analysis shows that task-scope is significant when either the task-uncertainty is zero or at the higher levels of task-coordination and uncertainty. From the above discussion, we can conclude that task-scope is really playing a significant role although exactly how it impacts the task as it is increased could not be teased out in this research. It appears that while different levels of the task-scope were designed into the task, it alone has little to no affect on performance. But it might be due to lack of physical workload in the team simulation task.

Therefore, task-scope might further be tested using a team task that has more physical and information workload than a team simulation game. Also, further work needs to be done in finding any other factors that could be grouped into task-scope. Appendix F shows actual SAS code written for statistical analysis.

### 5.1.5 Hypothesis 4

Differences in team task performance exist as task complexity is increased by the task coordination (number of coordination information flows and interactions).

Dependent Variable : team task-performance

Independent Variable : task-coordination

The objective of hypothesis 4 was to evaluate whether the task-coordination is affecting the team task-performance significantly as a task-dimension or not. Though partial regression analysis option was considered earlier, it did not provide enough degrees of freedom to validate the task-coordination and also, it is not robust. Since effects tests from the full multiple linear regression analysis evaluate all the main affects and interactions with the maximum degrees of freedom, there was no need for contrasts or partial regression analysis to test the hypothesis 4.

Results from effect tests indicate that the task-coordination is highly significant ($p < 0.0001$). Table 5.11 summarizes the hypothesis 4 results from the effect tests. This provides strong support for hypothesis 4 that task-coordination is a significant task-complexity dimension effectively contributing to the team performance both from the effect tests as well as from the significant 3-way interaction. Least square means plot of the task-coordination Vs task-performance is shown in the Figure 5.3. Table 5.12 shows that there was gradual decrease in the task performance means among the three task-coordination complexity levels. Least square means plot also indicates the same.

**Table 5.11 Effect Tests: Hypothesis 4**

| Source | DF | F Value | Pr > F | |
|---|---|---|---|---|
| **Coordination** | 2 | 2.91 | **<0.0001** | **Significant** |
| **Scope*Coordination*Uncertainty** | 8 | 2.87 | **0.0190** | **Significant** |

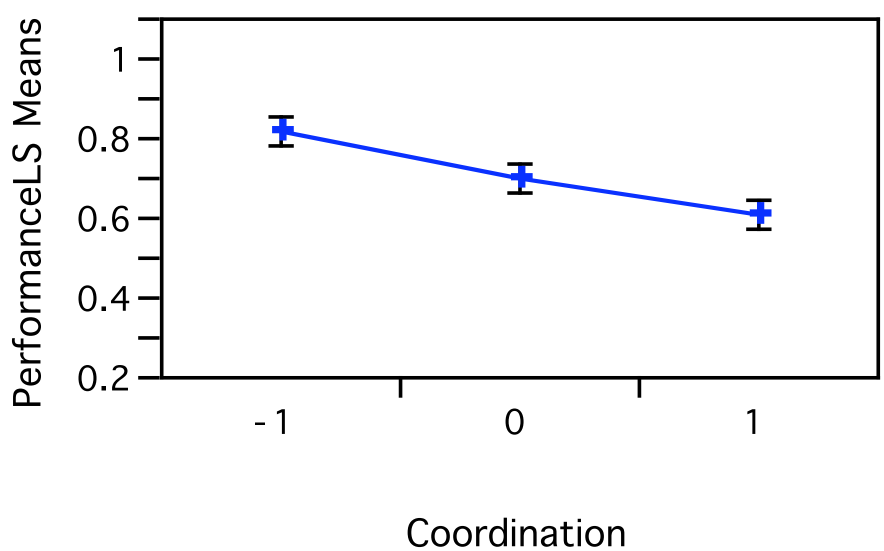



**Figure 5.3 Task-Coordination Vs Performance Least Square Means Plot**

**Table 5.12 Task-Coordination: Least Square Means**

| Level | Standard Error | Least Square Means: Task Performance |
|---|---|---|
| -1 | 0.0181 | 0.819 |
| 0 | 0.0181 | 0.702 |
| 1 | 0.0181 | 0.608 |

Therefore, it appears that while different levels of task-coordination were designed into the task, it has significant affect on performance. Hypothesis 4 shows that an increase in the number of coordination information flows and interactions causes a decrease in team performance. Results show that task-coordination is a highly significant dimension to task-complexity space and has heavy influence on the team performance. Appendix F shows actual SAS code written for statistical analysis.

### 5.1.6 Hypothesis 5

Differences in team task performance exist as task complexity is increased by amount of task-uncertainty (number of internal/external uncertainty and random events).

Dependent Variable : team task-performance

Independent Variable : task-uncertainty

The objective of hypothesis 5 was to evaluate whether the task-uncertainty is affecting the team task-performance significantly as a task-dimension or not. Though partial regression analysis option was considered earlier, it did not provide enough degrees of freedom to validate the task-uncertainty and also, it is not robust. Since effects tests from the full multiple linear regression analysis evaluate all the main affects and interactions with the maximum degrees of freedom, there was no need for contrasts or partial regression analysis to test the hypothesis 5.

Results from effect tests indicate that the task-uncertainty is highly significant (p < 0.0001). Table 5.13 summarizes the hypothesis 5 results from effect tests. This provides strong support for hypothesis 5 that task-uncertainty is a significant task-complexity dimension effectively contributing to team performance both from effect tests as well as from significant three-way interaction.. Least square means plot of the task uncertainty Vs task performance is shown in the Figure 5.4. Table 5.14 shows that though the medium (0) and high (1) task-uncertainty levels have similar team performance means, there was gradual decrease in the task performance means among the three task-uncertainty complexity levels. Least square means plot also indicate the same.

Therefore, it appears that while different levels of task-uncertainty were designed into the task, it has a significant effect on performance. Hypothesis 5 shows that an increase in the uncertainty (number of random events) causes a decrease in team performance. Results show that task-uncertainty is a highly significant dimension to task-complexity space and has heavy influence on the team performance. Appendix F shows actual SAS code written for statistical analysis.

**Table 5.13 Effect Tests: Hypothesis 5**

| Source | DF | F Value | Pr > F | |
|---|---|---|---|---|
| **Uncertainty** | 2 | 2.91 | **<0.0001** | **Significant** |
| **Scope*Coordination*Uncertainty** | 8 | 2.87 | **0.0190** | **Significant** |

**Table 5.14 Task-Uncertainty: Least Square Means**

| Level | Standard Error | Least Square Means: Task Performance |
|---|---|---|
| -1 | 0.0181 | 0.837 |
| 0 | 0.0181 | 0.632 |
| 1 | 0.0181 | 0.659 |

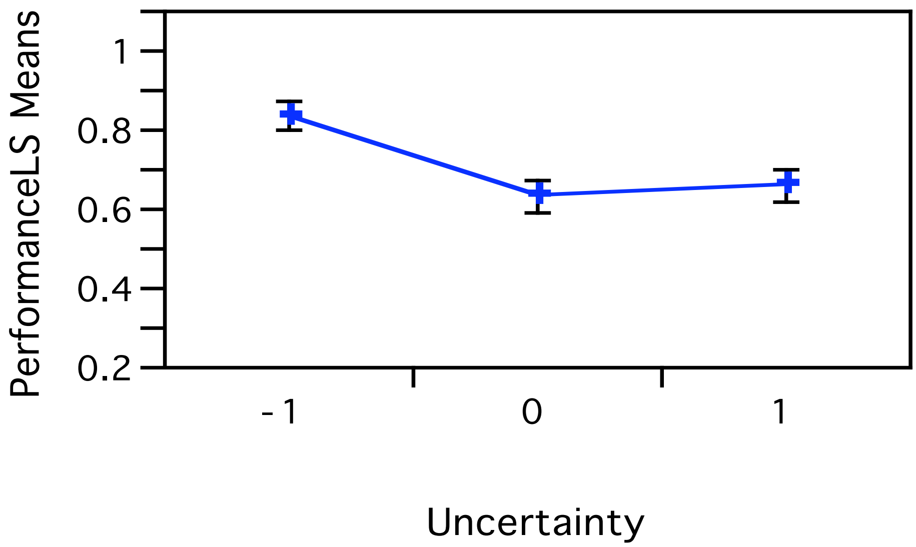



**Figure 5.4 Task-Uncertainty Vs Performance Least Square Means Plot**

### 5.1.7 Perceived Task Work Load Vs Team Performance

As explained earlier, this research proposed a model of task-complexity based on different task-characteristics including task-scope, task-coordination and task-uncertainty that provide the capability to quantify different attributes that impact team performance. In other words, team performance was studied from task-complexity perspective utilizing objective team performance measure (Time Windows) in this model. However, most of the previous teams' literature indicates the study and understanding of team performance from workload, a subjective performance measure, perspective.

From Teams' literature,

- An increase in workload (stress processes) causes a decrease in team performance due to factors such as cognitive, physical, and temporal stress processes.
- However, team performance will decrease only after reaching a certain limit of workload (Entin and Serfaty, 1999).
- Workload (stress processes) measure is used as subjective performance measure.

NASA Task Work Load Index (NASA TLX) was extensively used in teams' literature for gathering workload information to study team performances. Therefore, for cross validating this model, perceived task-workload survey (NASA TLX) was performed for gathering workload data from each participant team. After the experiment all the participant teams completed NASA TLX forms to capture their perceived workload of the experimental task. Since each participant teams consist of two people, an average of the two task workloads was considered as the representation of team task workload.

Task-complexity literature shows contradictory findings about the relationship between the task-complexity and task performance. But there is general feeling that both are negatively correlated to each other. So, any indication of negative correlation of the workload and task-performance supports and cross validates this model and the results of this research. Table 5.15 shows the pair-wise correlation analysis between perceived task-workload (NASA TLX) and task-performance. Refer to Appendix H for the perceived task-complexity data tables.

**Table 5.15 Pair-Wise Correlation: Work Load Vs Team Performance**

| Variable | by Variable | Pearson Correlation (r) | Count | Significant Probability |
|---|---|---|---|---|
| Work Load | Performance | -0.3203 | 54 | 0.0182 |

Results found a significant negative correlation ($r = -0.3203$, $p=0.0182$) between the perceived task-workload and the task-performance, thereby validating the model from the workload perspective. Therefore, it is evident from this correlation analysis that an increase in the task-complexity causes a decrease in the task-performance.

# CHAPTER 6

# SUMMARY AND CONCLUSIONS

The Research conducted within this thesis was intended to develop and validate a generalized task-complexity theory and framework by drawing on information from the literature, previous work related to task-complexity, and the current experiment. As this research comes to a close, it is important to reflect on the results, conclusions, why some hypotheses were supported and while others were not. Reflection allows one to step back and understand the importance of the research and the direction that should be taken in future research.

This chapter will first provide a brief overview of the major areas of literature. Next, theoretical and practical implications will be drawn from the experimental results. Last, Future work will be outlined to expand the knowledge of the engineering collaboration even further.

## 6.1 Reflections

### 6.1.1 Literature Reflection

Teams work in various work environments and domains solving complex problems. Since teams perform tasks to solve organizations problems and accomplish the objectives. To understand teams and tasks they perform require a broad understanding of the many team and task factors, and good understanding of their collaboration process. Tasks, which teams perform, are proven and considered as important moderators of team behavior and effectiveness. Since teams engage in many different collective activities, a number of task typologies and descriptions have been presented in the team related literature in an effort to better define and understand the critical role of the tasks and the associated team processes. Though there were many task typologies, the small group and team literature pointed out the importance to have a generalized team–tasks oriented approach that conceives different teams as embedded entities in a task-space developed based on the task context, task characteristics, and task-complexity. The management and communication literature pointed out that all team tasks require better understanding among the team members or coordination, and communication for rich interactions among the members. Thus the team coordination and team communication are important team factors to be considered in the generalized team–tasks oriented approach. Small group and teams literature also points out that there is no comparison mechanism, especially quantitative comparison, of team performance and teams working in various work environments need such mechanism for better task distribution, communication patterns and work interfaces design. If organizations are to be successful, we must create a generalized team theory and framework to evaluate the elements that impact individual and team performance as well as an individual's adaptability to technology changes.

## 6.2 Implications

This research has evaluated and validated the proposed generalized team- task-complexity model. Research yielded a significant negative correlation between task-complexity and task-performance, supporting the notion that an increase in task-complexity causes a decrease in team performance. The results of this research have both theoretical and practical implications for team collaboration in complex settings.

### 6.2.1 Theoretical Contribution

This experiment provides a clearer understanding of the team and task factors (or variables), grouped into three task-dimensions, which compose task-complexity and how these affect the task performance. It thoroughly validated influence of various levels of the proposed task-dimensions on task performance.

Hypothesis one, full model analysis, results support that the 3-way interaction of scope, coordination, and uncertainty was significant. In addition, the 2-way interaction between scope and uncertainty was found to be significant. The main effects, task-coordination and task-uncertainty were also found to be highly significant. Task-scope was not significant from the effects tests. Though task-scope was not significant, it had significant interaction with task-uncertainty. Significant 3-way interaction of the main effects and 2-way interaction of task-scope and task-uncertainty indicate that they have non-zero regression coefficients. As a result, regression coefficients of the main effects (scope, coordination and uncertainty) cannot have equal weight. In other words, hypothesis 1 informs that all the three dimensions were not equally contributing to the team task-complexity and task-performance.

Hypothesis two was intended to test that task-scope and task-coordination are minimum dimensions needed when uncertainty is negligible. Hypothesis two is drawn from the McGrath's (1984) definition of intellective tasks, which states that as tasks with known answers. Thus uncertainty is either negligible or zero for intellective tasks. Results from the analysis of 3-way interaction sliced by main effect task-uncertainty show that 2-way interaction of task-scope and task-coordination is significant when task-uncertainty was negligible or zero (at -1 level). Significant 2-way interaction of task-scope and task-coordination indicates that both are significant task-complexity dimensions when uncertainty is zero. 2-way interaction of task-scope and task-coordination also indicate that it has non-zero regression coefficient. As a result, regression coefficients of the task-scope and task-coordination cannot have equal weight. In other words, hypothesis 2 informs that the two dimensions, scope and coordination, were not equally contributing to the team task-complexity and task-performance.

Task-scope dimension consists of two factors, number of sub-tasks and amount of information processed. Teams that worked in less uncertainty and coordination seemed to be quite successful irrespective of levels of task-scope. Team literature indicates that an increase in number of tasks or amount of information processed causes more complexity. Contrary to earlier researchers' (Steiner, 1972; Wood, 1986; Campbell, 1988) findings, task-scope is slightly significant at higher task-complexity levels. But its 2-way interaction with task-uncertainty as well as 3-way interaction point out that it is still a major task dimension. Thus, hypothesis two together with 3-way interaction analysis shows that task-scope is significant when either task-uncertainty is zero or higher levels of task-coordination and task-uncertainty. From the above discussion, we can conclude that task-scope is in fact playing a significant role although exactly how it impacts the task as it is increased could not be teased out in this research. It appears that while different levels of task-scope were designed into the task, it alone has little to no affect on the performance. But it might be due to lack of physical workload in the selected TASP team simulation task. Thus, task-scope might further be tested using a team task that has more physical and information workload than a team simulation game. Though all these clearly indicate that task-scope is significant enough, more thorough evaluation and testing might be needed in future. Also, further work needs to be done in finding any other factors that could be grouped into task-scope.

Hypothesis four results indicate that while different levels of task-coordination were designed into the task, it has significant affect on performance. In other words, hypothesis four shows that an increase in the number of coordination information flows and interactions causes a decrease in team performance. Results show that task-coordination is highly significant dimension to task-complexity space and has heavy influence on the team performance.

This research has shown that task-coordination is a highly significant dimension to task-complexity space and has heavy influence on the team performance. In terms of coordination needed for accomplishing team tasks, hypothesis four shows that an increase in number of coordination information flows and interactions lead to a decrease in performance. Therefore, hypothesis four results agree with the supporting literature (Wood, 1986; Chen and Lin, 2003). Since the coordination needs a communication medium for information flows and interactions, hypothesis four shows that the latest collaboration tools and groupware need to address the ways to reduce the number of interactions and information flows to accomplish the team tasks.

Hypothesis five results supported the literature that indicates that uncertainty related to relationship of sub-tasks, organizational external constraints, and unexpected events increases the task complexity (Perrow, 1967; daft and Macintosh, 1981; Daft and Lengel, 1986; Wood, 1986; Wood, 1988; Campbell, 1988; Specier, Vessey, and Valacich, 2003). Results show that task-uncertainty is a highly significant dimension to task-complexity space and has heavy influence on the team performance. Therefore, it appears that while different levels of task-uncertainty were designed into the task, it has a significant effect on the performance. Hypothesis five results show that an increase in the uncertainty (number of random events) causes a decrease in the team performance.

In this model, team performance was studied from task-complexity perspective utilizing objective team performance measure (Time Windows). However, most of the previous teams' literature indicates the study and understanding of team performance from workload, a subjective performance measure perspective. From teams' literature, an increase in workload (stress processes) causes a decrease in team performance due to factors such as cognitive, physical, and temporal stress processes. However, team performance will decrease only after reaching a certain limit of workload (Entin and Serfaty, 1999). Task-complexity literature shows contradictory findings about the relationship between the task-complexity and task performance. But there is general feeling that both are negatively correlated to each other. Therefore, any indication of negative correlation of the workload and task-performance supports and cross validates this model and the results of this research from workload perspective. The results from pair-wise correlation analysis between perceived task-workload (NASA TLX) and task-performance clearly indicated a significant negative correlation between them. Though teams' literature shows contradictory findings about the relationship between the task-complexity and task performance, the findings of this research supports the general research community feeling of possible negative correlation between them. Thus, it is clearly evident from this correlation analysis that an increase in the task-complexity causes a decrease in the team performance.

This research was intended to develop a generalized team model from a task-complexity perspective. The theoretical contribution of this research is a broader understanding of the human and technology aspects of collaboration through a generalized team task-complexity approach. It begins to clarify the task and team attributes (or factors) and their influence on people performing collaborative tasks under various working domains. This generalized team–tasks oriented approach conceives different teams as embedded entities in a task-space developed on team and task attributes such as the task context, task characteristics, information processing, coordination, communication and uncertainty. This generalized approach provides the comparison mechanism platform, especially quantitative comparison, of team performance. Teams working in various work environments need such quantitative comparison mechanism for better task distribution, communication patterns and work interfaces design. If organizations are to be successful, this generalized team theory and framework must further evaluate and validate the elements that impact individual and team performance as well as an individual's adaptability to technology changes in various task environments and domains.

### 6.2.2 Practical Contributions

In additional to the theoretical contribution, the model provides a practical contribution. This research towards generalized team task-complexity model was validated thoroughly in the military command and control domain. What the results tell organizations is that an increase in coordination information flows and interactions increase task-complexity and decrease team performance. Since the coordination needs a communication medium for information flows and interactions in today's organizations, it has practical application in the design of latest collaboration tools and groupware. Next generation of collaboration tools and groupware could be designed by addressing the ways to reduce the number of coordination information flows and interactions necessary for effectively completing tasks. Further, results related to coordination information flows could also be extended for comparison of the complexity contributed by these collaboration tools and testing their usefulness of improving the team performance.

Upon successfully validating this generalized team task-complexity model in various complex task environments and domains, huge knowledge base of heuristics could be built utilizing the information related to division of work or tasks, task allocation and task performance. This has lot of potential application in team training, which has lot of importance in the present day intelligent warfare and military operations such as Close-Air-Support (CAS).

As organizations enter the 21$^{st}$ century, the source of competitive advantage is increasingly human resources. This may sound strange in a technological age where machines do more and more of the work, but it is precisely technology that creates this dependence on human resources. This is because technology is knowledge-driven. Given that the key problem in division of labor is the assignment of people with certain competencies and interests to tasks, organizations could also utilize such knowledge base for better work organization and team building.

Additionally, caution must be exercised in the transferability of these results to real-world tasks. The experimental tasks were designed to simulate real world tasks with an appropriate level complexity. However, real-world tasks are likely to be far more complex and expansive than the experimental tasks. Likewise, teams that have worked together for an extended amount of time and developed a strong understanding and coordination may not experience the same type of effects as the experimental groups. Therefore, the results of this research should be matched against a particular team's task and development to draw conclusions of its applicability to a real-world situation.

### 6.2.3 Limitations of the Current Model

The generalized team task complexity model was validated in military command and control domain only. However, it does lay strong task complexity space and framework for understanding teams working in any complex task environment or domain. To fully validate this generalized team task-complexity theory and model will require further empirical study in various task environments and domains. Also task-scope has to be defined further and vigorously tested of its validity as task complexity dimension. This research is just an initial step to developing a comprehensive understanding of team collaboration and team performance from task-complexity perspective.

## 6.3 Future Directions

No research answers all the questions and in most cases raises more questions. This research is no different. Three main areas are of primary interest in future.

The first area that needs further investigation is concrete definition task-scope attributes. Further study should look at defining the chunks (information chunks) of work into sub-tasks and develop heuristics to assist defining them. Once a mechanism of defining the sub-tasks is developed that framework could be useful in comparison of various team tasks.

The second area that needs further investigation is the development of a synthetic collaborative system that would emulate certain complex work environments and would enable the collection of team performance data for assessing hypotheses about collaboration. This synthetic system would allow researchers to vary aspects of (a) work processes (task complexity, distribution of tasks between operators, distribution of decisions between the operator(s), individual vs. team planning); (b) team interaction environment (communication medium, interaction patterns, information sharing, communication to support team awareness); and (c) work center interfaces (individual and team elements of interfaces, information presentation methods). Varying the environment would allow researchers to evaluate the elements that impact individual and team performance as well as an individual's adaptability to technology changes.

The third area that needs further investigation is the study of the influences of certain well-defined team inspiration factors, team size and gender factors on the team performance. This would further make the generalized team task complexity model more comprehensive and useful in the comparison of team performances under various work environment settings.

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## APPENDIX A

## PARTICIPANT REQUEST POSTER

**Study Title: Towards A Generalized Team Task-Complexity Model**

Volunteer 2-person teams (Both Male or Both Female) are requested for my study on "Teams and how they perform under various complexity levels"

**Who can be participants?**

- Graduate or undergraduate students with normal or corrected to normal vision
- Any one with Basic exposure of working as teams for their class projects
- Any one with Basic knowledge of playing computer/video games

**Experiment Description:**

- The experiment is a Military Team Simulation Game which requires 'two' persons to play
- One of the participant acts as a Team Leader and another acts as a Team Member
- The experiment consists of a training stage and actual experimental stage
- Total duration is 2 hours

**Experiment Location:**

3413 CEBA Building

**Contact:**

Ashok Darisipudi

Email ID: adaris1@lsu.edu

Phone: (225) 578-5378

# APPENDIX B

# PERSONAL INFORMATION AND PRIOR EXPERIENCE QUESTIONNAIRE

**Personal Information and Prior Experience Questionnaire**

**Part A: Personal Information**

Participant Name: _______________

Gender: _______________

Age: _______________

Is your experiment partner:

A Friend     Just A Classmate     I don't know him/her     (Circle any one of them)

Did you ever worked on any projects with your experimental partner in a team?

Yes     No     (Circle any one of them)

Degree pursuing:     Undergraduate     Graduate     PhD     (Circle any one of them)

Year of Study:     First     Second     Third     Fourth     Five or More (Circle any one of them)

**Part B: Basic Exposure and Knowledge**

Please **circle one** response that best represents your opinion to the following questions.

Do you like working in teams?

Yes     No

Did you ever worked in team projects/assignments in your coursework?

Yes     No

If yes, so far how many team projects you worked on?

1 - 3     4 - 6     7 - 9     10 - 12     12 or more

How much time you spend on computers and internet every week?

0 – 5 hrs     6 – 10 hrs     11 – 15 hrs     16 – 20 hrs     20 or more hrs

Do you play video/computer games?

Yes No

If yes, how often do you play?

Daily 2-3 times a Week Once a Week 2-3 times a Week Once a Month Rarely Ever

Did you ever play any team video/computer games?

Yes No

If yes, how often do you play?

Daily 2-3 times a Week Once a Week 2-3 times a Week Once a Month Rarely Ever

# APPENDIX C

# EXPERIMENT RULES OF ENGAGEMENT

**<u>Rules of Engagement/Standing Orders (in order of importance):</u>**

1. Engage aircraft (at 20 NM; hostile or assumed hostile aircraft only).
2. Assign/Illuminate aircraft (at 30 NM; hostile or assumed hostile only).
3. Maintain safety of DCA (e.g., keep DCA away from danger zones of hostile aircraft, don't let DCA run out of fuel, etc.).
4. Issue Level 1 warning (at 50 NM; hostile or assumed hostile only).
5. Issue Level 2 warning (at 40 NM; hostile or assumed hostile only).
6. Issue Level 3 warning (at 30 NM; hostile or assumed hostile only).
7. Keep DCA within 256 NM from ownship.
8. Keep DCA at least 20 NM away from ownship.
9. Make a primary identification of air contact (i.e., friendly, hostile, assumed hostile/friendly).
10. Make an AIR identification of air contact (i.e., strike, missile platform, AEW, etc.).

* Once an aircraft has come within 50 NM from ownship, it should be identified before it travel an excess of 10 NM. If an aircraft "pops up" within 50 NM it should be identified before it travels an excess of 10 NM.

**Two overarching rules:**

• Defend ownship and ships in battle group.

• Do not engage friendly or civilian aircraft.

## Identifying a track

The team is only responsible for the identification of unknown *AIR* tracks, which includes the intent (hostile or friendly) and the type (helicopter, strike, etc.).

- Pieces of information that can be used to help make an identification include:

  1. **IFF**- Identify Friend/Foe can only be used if the track is within 150 Nautical Miles of ownship. This information must be requested.
  2. **EWS** - Radar sensor information must be requested.
  3. **Point of Origin** of the unknown track – see the map associated with each scenario to locate hostile nations.
  4. **Speed**
  5. **Altitude**
  6. **Range** how far a track is from ownship
  7. **Course** direction the track is heading (in degrees)
  8. **Bearing** location of track relative to ownship

For example, if an unknown air track has a speed of 430 knots and an altitude of 30,000 ft it is *probably* a commercial airliner.

- The following symbols are used to distinguish between types of tracks:

| | Unknown | Friendly | Hostile |
|---|---|---|---|
| **Air** | | | |
| **Surface** | | | |
| **Subsurface** | | | |

X represents a landmark.

represents an assumed friendly air track.

E represents an assumed hostile air track.

T represents a tanker.

C Represents a commercial airliner.


---

**<u>TASP Air Track Abbreviations:</u>**

| | |
|---|---|
| **DCA:** Defensive Counter Air. DCA can be fighters or interceptors with only air-to-air weapons | **Non-military:** Civilian transport aircraft |
| **Tanker:** Tanker. Tankers are refueling planes. | **Clutter:** Radar signature of a non-platform object such as a bird or sandstorm |
| **Helo:** Helicopter | |

**<u>Resources to aid in the identification of air tracks:</u>**

I. **EWS** - Sensor information about a track may be available. The AAWC may request this directly from his/her main menu ("Sensor Status"). The AIC may request it by going through the Backup-AAWC menu.

- This information will help you decide on the intent of the aircraft (hostile or friendly) and the type of aircraft (DCA, strike, helo, etc.).
- Please note that certain aircraft do not have radar sensors and others may not have their radar sensors turned on. For these aircraft, your EWS report will be negative ESM.
- Four types of radar sensors listed in the tables can either be friendly or hostile. Other types of information must be used to make an identification.
- Please refer to the table to interpret EWS reports:

| **FRIENDLY SUMMARY** | | **HOSTILE SUMMARY** | |
|---|---|---|---|
| **PLATFORM** | **SENSOR** | **PLATFORM** | **SENSOR** |
| **DCA:**<br>F-15 (Eagle) | APG-63 | **DCA:**<br>MIG-25 (Foxbat A)<br>MIG-31 (Foxhound) | FOXFIRE<br>FLASHDANCE |
| **HELO:**<br>LAMPS III | APS-124 | **HELO:**<br>KA-25 | BIG BULGE |
| **NON-MILITARY:**<br>BOEING 727<br>GULF STREAM II | ARINC564<br>PRIMUS 40 | | |

**<u>Resources to aid in the identification of air tracks:</u>**

II. **IDS** - Identify Friend/Foe information about a track may be available. The AAWC may request this directly from his/her main menu ("IFF"). The AIC may request it by going through the Backup-AAWC menu.

- The IFF system indicates the self-identity of a craft. An IFF challenge will result in the AAWC obtaining the *self-reported* friend/foe status of the challenged craft. Therefore, the report you receive may be deceptive.
- Aircraft can emit a signal on one of the modes, on all three modes, or none of the modes.

- IFF information can only be queried when the track is within 150 NM of ownship.
- Aircraft that is not "squawking" (providing information) after an IFF challenge could be identified as hostile. NOTE: Missiles do not respond to an IFF challenge (other resources must be used to identify this type of aircraft).
- **Mode 1:** consists of a 2-digit military identifier of the task group.
- **Mode 2:** consists of a 4-digit military identifier of the specified unit. For example, an aircraft that is emitting a mode 2: 5438 signal could be identified as a friendly strike (F/A-18). See table below:

| **FRIENDLY SUMMARY** | | **HOSTILE SUMMARY** | |
|---|---|---|---|
| DCA: F-15 | 20## | DCA: N/A | |
| HELO:LAMPS III | 10## | **HELO:** KA-25 | 12## |

- **Mode 3:** consists of a 3 to 4-digit military/civilian identifier for the Air Traffic Control (ATC). In civilian cases, it is the flight number.

**Resources to aid in the identification of air tracks:**

III. While EWS and IFF may not be available for every track, the following are continuously available on all tracks and can be found in the character readout box (located in the upper left-hand corner of the screen):

| | |
|---|---|
| **Course** | **Point of origin** of the unknown track (can be determined by using the map) |
| **Bearing** | **Speed** |
| **Range** from ownship. | **Altitude** |

**Note:**

| FRIENDLY SUMMARY | | HOSTILE SUMMARY | |
|---|---|---|---|
| **PLATFORM** | **SPEED** | **PLATFORM** | **SPEED** |
| **DCA:** | | **DCA:** | |
| F-15 (EAGLE) | 1433 mph | MiG-25 | 1606 mph |
| | | MiG-31 | 1305 mph |
| **HELO:** | | **HELO:** | |
| LAMPS III | 200 mph | KA-25 | 115 mph |
| **NON-MILITARY:** | | | |
| BOEING 727 | 600 mph | | |
| GULFSTREAM II | 600 mph | | |

**Note:**

| COMMON PROFILES | | |
|---|---|---|
| **Platform** | **Altitude** | **Speed** |
| Commercial Airliner | 28000-34000 ft<br>35000-37000 ft (Intercontinental) | 400-450 knots |
| HELO | 100-2500 ft | 50-200 knots |

## APPENDIX D

## CONSENT FORM

**LOUSIANA STATE UNIVERSITY-BATON ROUGE CAMPUS**

**CONSENT FORM**

1. **Study Title:** Towards A Generalized Team Task-Complexity Model

2. **Performance Site:** CEBA, 3413 CHaMP Lab
Dept. of Industrial and Manufacturing Systems Engineering
Louisiana State University A&M College
Baton Rouge, LA 70803

3. **Investigators:** The following investigators are available for questions about this study:

Ashok Darisipudi
PhD Student
Dept. of Industrial and Manufacturing Systems Engineering
3413 CEBA Building, Louisiana State University
Baton Rouge, LA 70803
Telephone Number: (225) 578-5378

Dr. Craig Harvey
Asst. Professor
Dept. of Industrial and Manufacturing Systems Engineering
3135A, CEBA Building, Louisiana State University
Baton Rouge, LA 70803
Telephone Number: (225) 578-5364

4. **Purpose of the Study:**

Today's organizations are increasingly using teams to streamline processes, enhance participation, and improve quality. The use of teams in organizations has expanded dramatically in response to complex problems and to get a competitive edge over the competitors. Irrespective of private or public sector organizations, the reliance on teams and work groups is present. With ‘teams’ comes the ‘task’ that they need to perform in order to solve the organizational problems. Since teams engage in many different collective activities, a number of task typologies and descriptions have been presented in the team related literature in an effort to better define and understand the critical role of the tasks and the associated team processes.

This thesis proposes to define the underlying dimensions that compose a task which contribute to complexity in a team environment. Team literature shows that several dimensions potentially represent task complexity. For the purpose of this thesis, these variables are grouped into three complexity dimensions: task-scope, task-coordination, and task-uncertainty. These complexity dimensions are hypothesized to affect the teams’ task performance. This research focuses on how any team task can be represented in a team task-complexity space of three dimensions and how these dimensions affect team performance in any task environment. Considering the practical difficulty of experimentally testing many team-tasks from different domains, a thorough validation of these task-dimensions is done my experimentally testing a number of team-tasks designed within a particular selected domain of command and control. A Java-Based two-role team simulation known as TASP is used for testing different task-complexity scenarios. Team performance measures will be captured by the simulation software itself and will be evaluated for team performance using convert software and scoring criteria.

**5. Subject Inclusion:**

Graduate or undergraduate students with normal or corrected to normal vision at Louisiana State University who have basic exposure of working as teams for their class projects and basic knowledge of playing computer/video games will participate in study.

**6. Number of subjects:** 108 (54 two-member teams)

**7. Study Procedures:**

The experimental procedure is a two-stage procedure comprising the training stage and experimental stage. The participant team will be subjected to meet a minimum amount of team performance in order to participate in the experimental stage. This helps in fulfilling the condition of all teams of having sufficient knowledge in performing the experimental task and avoids the possibility of inconsistency. In the training stage, teams consisting of two participants first complete initial data forms (subject information, experiment consent form, and prior experience questionnaire). Upon completion of these forms, teams will be given the experimental task description and guidelines packet that consists of Rules of Engagement (ROEs) and other technical information to be remembered in order to perform TASP simulation tasks. The participant team will undergo a 50-minute training session, comprising of two training tasks, to acclimate them to the TASP simulation environment. Each training task is of 20 minutes duration with a 10-minute break in between them. Participants will be informed to come for second stage, experimental stage, provided they meet the minimum team performance requirement. Experimental stage consists of a quick review and performing actual experimental task scenario of 30 minutes duration followed by post-experimental data collection (team satisfaction survey and perceived task-workload survey).

**8. Benefits:**

There will not be any direct health, monetary or mental benefits to the individual participant. But the results of the study may be beneficial to the greater population as it leads to a better understanding of how any team will perform in complex situations and environments.

**9. Risks:**

Participants will experience no risks greater than those from operating a personal computer.

**10. Measures to reduce the risk:**

All the simulation tasks have a maximum duration of 30 minutes only there by avoiding chances of participants feeling any fatigue. Apart from that break periods are provided before performing any simulation tasks.

**10. Right to Refuse:**

Subjects may choose not to participate or if at any time during the study, subject feels uncomfortable with any method or performing the requirements, formal withdrawal from the study will commence at any time without any penalty.

**11. Privacy:**

If the results of present study are published, names or identifying information of the subjects will not be included in the publication. Subject identity will remain secret unless disclosure is required by law. The data will be stored in a locked cabinet or password-secured computer. The screening questionnaires of rejected subjects will be destroyed.

**12. Financial Information:**

Subjects or volunteers and will not be compensated for participation in this study.

## CONSENT FORM

**13. Signature:**

The study procedure has been completely explained to me and all my questions have been answered. I have understood the procedure and if I have additional questions regarding study specifics I may direct them to investigator. If I have questions about subjects' rights or other concerns, I can contact Robert C. Mathews, Institutional Review Board, and (225) 578-8692. I agree to participate in the present study and acknowledge the investigator's obligation to provide me with a signed copy of this consent form.

**Signature of Subject** **Date**

# APPENDIX E

# PERCEIVED TASK-WORKLOAD (NASA TLX)

TASK LOAD INDEX (NASA-TLX)

SUBJECT RATING INSTRUCTIONS

| NASA-TLX RATING SCALE DEFINITIONS | | |
|---|---|---|
| Title | Endpoints | Descriptions |
| MENTAL DEMAND | *Low/High* | How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving? |
| PHYSICAL DEMAND | *Low/High* | How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious? |
| TEMPORAL DEMAND | *Low/High* | How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic? |
| PERFORMANCE | *Good/Poor* | How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals? |
| EFFORT | *Low/High* | How hard did you have to work (mentally and physically) to accomplish your level of performance? |
| FRUSTRATION LEVEL | *Low/High* | How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task? |

Mweights

Direction: Select, by encircling, which was a more important contributor to workload for you.

| Combination | Workload Factors | |
|---|---|---|
| 1 | Frustration | Performance |
| 2 | Mental Demand | Performance |
| 3 | Frustration | Physical demand |
| 4 | Effort | Frustration |
| 5 | Physical demand | Effort |
| 6 | Effort | Temporal Demand |
| 7 | Temporal Demand | Frustration |
| 8 | Physical demand | Mental Demand |
| 9 | Performance | Temporal Demand |
| 10 | Frustration | Mental Demand |
| 11 | Physical demand | Temporal Demand |
| 12 | Performance | Physical Demand |
| 13 | Mental Demand | Effort |
| 14 | Performance | Effort |
| 15 | Mental Demand | Temporal Demand |

Rate each of the following workload factors by encircling the ratings value below

| WORKLOAD FACTORS | RATINGS | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mental Demand | LOW | | | | | | | | | | | | | | | | | | HIGH |
| | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 | 6.5 | 7 | 7.5 | 8 | 8.5 | 9 | 9.5 | 10 |
| | | | | | | | | | | | | | | | | | | | |
| Physical Demand | LOW | | | | | | | | | | | | | | | | | | HIGH |
| | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 | 6.5 | 7 | 7.5 | 8 | 8.5 | 9 | 9.5 | 10 |
| | | | | | | | | | | | | | | | | | | | |
| Temporal Demand | LOW | | | | | | | | | | | | | | | | | | HIGH |
| | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 | 6.5 | 7 | 7.5 | 8 | 8.5 | 9 | 9.5 | 10 |
| | | | | | | | | | | | | | | | | | | | |
| Performance | GOOD | | | | | | | | | | | | | | | | | | POOR |
| | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 | 6.5 | 7 | 7.5 | 8 | 8.5 | 9 | 9.5 | 10 |
| | | | | | | | | | | | | | | | | | | | |
| Effort | LOW | | | | | | | | | | | | | | | | | | HIGH |
| | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 | 6.5 | 7 | 7.5 | 8 | 8.5 | 9 | 9.5 | 10 |
| | | | | | | | | | | | | | | | | | | | |
| Frustration | LOW | | | | | | | | | | | | | | | | | | HIGH |
| | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 | 6.5 | 7 | 7.5 | 8 | 8.5 | 9 | 9.5 | 10 |

# APPENDIX F

# SAS CODE FOR STATISTICAL ANALYSIS

```
dm "output;clear;log;clear";

Options LS=120 PageNo=1;

ODS Listing Close;

ODS Results Off;

ODS RTF File="Ashok.rtf";


Data Ashok;

 Input Run Scope Coordination Uncertainty t1 t2 @;

 Input Score @; Output;

 Input Score; Output;

DataLines;

1     -1    -1    -1    10    10    1     1

2     -1    -1    0     8     8     0.8   0.8

3     -1    -1    1     7     8     0.7   0.8

4     -1    0     -1    8     8     0.8   0.8

5     -1    0     0     5     5     0.5   0.5

6     -1    0     1     7     7     0.7   0.7

7     -1    1     -1    8     7     0.8   0.7

8     -1    1     0     5     5     0.5   0.5

9     -1    1     1     5     3     0.5   0.3

10    0     -1    -1    18    19    0.9   0.95

11    0     -1    0     15    13    0.75  0.65

12    0     -1    1     18    15    0.9   0.75
```

```
13	0	0	-1	14	14	0.7	0.7

14	0	0	0	18	15	0.9	0.75

15	0	0	1	14	13	0.7	0.65

16	0	1	-1	14	17	0.7	0.85

17	0	1	0	11	15	0.55	0.75

18	0	1	1	15	11	0.75	0.55

19	1	-1	-1	28	28	0.933	0.933

20	1	-1	0	24	23	0.8	0.767

21	1	-1	1	20	22	0.667	0.733

22	1	0	-1	27	26	0.9	0.867

23	1	0	0	14	18	0.467	0.6

24	1	0	1	22	20	0.733	0.667

25	1	1	-1	24	22	0.8	0.733

26	1	1	0	10	17	0.333	0.567

27	1	1	1	18	14	0.6	0.467

;

Proc Print Data=Ashok;

Run;

/*

Proc Means Data=Ashok N Mean Min Max;

Class Scope Coordination Uncertainty;

Var Score;

Run;
```

```
Proc Mixed Data=Ashok Method=Type3;
 Class Scope Coordination Uncertainty;
 Model Score = Scope | Coordination | Uncertainty / Solution;
 Contrast "Scope" Scope 1 -1 0,
                  Scope 1  0 -1;
* LSMeans Scope*Coordination*Uncertainty /
   Slice=(Scope*Coordination Scope*Uncertainty Coordination*Uncertainty
          Scope Coordination Uncertainty);
* LSMeans Scope*Coordination*Uncertainty / PDiff Adjust=Tukey;
  LSMeans Coordination*Uncertainty;
Run;
*/
Proc GLM Data=Ashok;
 Class Scope Coordination Uncertainty;
 Model Score = Scope | Coordination | Uncertainty / Solution;
* Contrast "Scope" Scope 1 -1 0,
                  Scope 1  0 -1;
 LSMeans Scope*Coordination*Uncertainty /
   Slice=(Scope*Coordination Scope*Uncertainty Coordination*Uncertainty
          Scope Coordination Uncertainty);
 LSMeans Scope*Coordination*Uncertainty / PDiff Adjust=Tukey;
*  LSMeans Coordination*Uncertainty;
```

```
Run; Quit;


Proc GLM Data=Ashok;
 Where Uncertainty=-1;
 Class Scope Coordination ;
 Model Score = Scope | Coordination  / Solution;
* Contrast "Scope" Scope 1 -1 0,
                   Scope 1  0 -1;


 LSMeans Scope*Coordination /
 Slice=(Scope Coordination);
 LSMeans Scope*Coordination / PDiff Adjust=Tukey;
*  LSMeans Coordination*Uncertainty;


Run; Quit;
ODS RTF Close;
ODS Results On;
ODS Listing;
```

# APPENDIX G

# TASK PERFORMANCE DATA TABLE

**Task Performance Data Table**

| Run Number | Task scope | Task co-ordination | Task un-certainty | Team Task performance | |
|---|---|---|---|---|---|
| | | | | Repetition 1 | Repetition2 |
| 1 | -1 | -1 | -1 | 1 | 1 |
| 2 | -1 | -1 | 0 | 0.8 | 0.8 |
| 3 | -1 | -1 | 1 | 0.7 | 0.8 |
| 4 | -1 | 0 | -1 | 0.8 | 0.8 |
| 5 | -1 | 0 | 0 | 0.5 | 0.5 |
| 6 | -1 | 0 | 1 | 0.7 | 0.7 |
| 7 | -1 | 1 | -1 | 0.8 | 0.7 |
| 8 | -1 | 1 | 0 | 0.5 | 0.5 |
| 9 | -1 | 1 | 1 | 0.5 | 0.3 |
| 10 | 0 | -1 | -1 | 0.9 | 0.95 |
| 11 | 0 | -1 | 0 | 0.75 | 0.65 |
| 12 | 0 | -1 | 1 | 0.9 | 0.75 |
| 13 | 0 | 0 | -1 | 0.7 | 0.7 |
| 14 | 0 | 0 | 0 | 0.9 | 0.75 |
| 15 | 0 | 0 | 1 | 0.7 | 0.65 |
| 16 | 0 | 1 | -1 | 0.7 | 0.85 |
| 17 | 0 | 1 | 0 | 0.55 | 0.75 |
| 18 | 0 | 1 | 1 | 0.75 | 0.55 |
| 19 | 1 | -1 | -1 | 0.933 | 0.933 |
| 20 | 1 | -1 | 0 | 0.8 | 0.767 |
| 21 | 1 | -1 | 1 | 0.667 | 0.733 |
| 22 | 1 | 0 | -1 | 0.9 | 0.867 |
| 23 | 1 | 0 | 0 | 0.467 | 0.6 |
| 24 | 1 | 0 | 1 | 0.733 | 0.667 |
| 25 | 1 | 1 | -1 | 0.8 | 0.733 |
| 26 | 1 | 1 | 0 | 0.333 | 0.57 |
| 27 | 1 | 1 | 1 | 0.6 | 0.467 |

# APPENDIX H

# PERCEIVED WORKLOAD DATA TABLE (NASA TLX)

## Perceived Work Load Data Table (NASA TLX)

| Run Number | Scope | Coordi nation | Uncert ainity | Team1 (Run1) | | Team Work Load | Team2 (Run2) | | Team Work Load | Avg Total Team Work Load |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | AAWC | AIC | | AAWC | AIC | | |
| 1 | -1 | -1 | -1 | 0.2 | 0.213 | 0.207 | 0.327 | 0.213 | 0.27 | 0.238 |
| 2 | -1 | -1 | 0 | 0.327 | 0.307 | 0.317 | 0.497 | 0.53 | 0.513 | 0.415 |
| 3 | -1 | -1 | 1 | 0.693 | 0.71 | 0.7017 | 0.42 | 0.47 | 0.445 | 0.573 |
| 4 | -1 | 0 | -1 | 0.397 | 0.447 | 0.4217 | 0.333 | 0.36 | 0.347 | 0.384 |
| 5 | -1 | 0 | 0 | 0.64 | 0.677 | 0.658 | 0.313 | 0.403 | 0.3583 | 0.508 |
| 6 | -1 | 0 | 1 | 0.467 | 0.453 | 0.46 | 0.387 | 0.46 | 0.423 | 0.4417 |
| 7 | -1 | 1 | -1 | 0.68 | 0.493 | 0.587 | 0.393 | 0.577 | 0.485 | 0.5358 |
| 8 | -1 | 1 | 0 | 0.573 | 0.62 | 0.597 | 0.313 | 0.307 | 0.31 | 0.453 |
| 9 | -1 | 1 | 1 | 0.567 | 0.65 | 0.608 | 0.413 | 0.48 | 0.447 | 0.5275 |
| 10 | 0 | -1 | -1 | 0.707 | 0.72 | 0.713 | 0.537 | 0.64 | 0.588 | 0.651 |
| 11 | 0 | -1 | 0 | 0.377 | 0.487 | 0.4317 | 0.597 | 0.73 | 0.663 | 0.5475 |
| 12 | 0 | -1 | 1 | 0.673 | 0.597 | 0.635 | 0.527 | 0.453 | 0.49 | 0.5625 |
| 13 | 0 | 0 | -1 | 0.553 | 0.433 | 0.493 | 0.753 | 0.573 | 0.663 | 0.578 |
| 14 | 0 | 0 | 0 | 0.74 | 0.64 | 0.69 | 0.547 | 0.713 | 0.63 | 0.66 |
| 15 | 0 | 0 | 1 | 0.777 | 0.447 | 0.7 | 0.657 | 0.63 | 0.643 | 0.6275 |
| 16 | 0 | 1 | -1 | 0.52 | 0.6 | 0.56 | 0.327 | 0.44 | 0.383 | 0.4717 |
| 17 | 0 | 1 | 0 | 0.69 | 0.617 | 0.653 | 0.673 | 0.61 | 0.6417 | 0.6475 |
| 18 | 0 | 1 | 1 | 0.613 | 0.52 | 0.567 | 0.463 | 0.383 | 0.423 | 0.495 |
| 19 | 1 | -1 | -1 | 0.467 | 0.477 | 0.4717 | 0.527 | 0.57 | 0.548 | 0.51 |
| 20 | 1 | -1 | 0 | 0.78 | 0.793 | 0.787 | 0.797 | 0.56 | 0.678 | 0.7325 |
| 21 | 1 | -1 | 1 | 0.533 | 0.47 | 0.5017 | 0.733 | 0.707 | 0.72 | 0.611 |
| 22 | 1 | 0 | -1 | 0.737 | 0.66 | 0.698 | 0.697 | 0.687 | 0.6917 | 0.695 |
| 23 | 1 | 0 | 0 | 0.723 | 0.793 | 0.758 | 0.827 | 0.723 | 0.775 | 0.767 |
| 24 | 1 | 0 | 1 | 0.773 | 0.627 | 0.7 | 0.667 | 0.607 | 0.637 | 0.668 |
| 25 | 1 | 1 | -1 | 0.483 | 0.527 | 0.505 | 0.64 | 0.773 | 0.707 | 0.6058 |
| 26 | 1 | 1 | 0 | 0.827 | 0.713 | 0.77 | 0.727 | 0.767 | 0.747 | 0.758 |
| 27 | 1 | 1 | 1 | 0.743 | 0.777 | 0.76 | 0.753 | 0.727 | 0.74 | 0.75 |

# VITA

Ashok Darisipudi was born in Pithapuram, a small cultural town famous for renowned philanthropic, film personalities and musicians in Andhra Pradesh, India. He completed his high school education in P.R. Government High School, Kakinada. He ranked 6$^{th}$ among 10$^{th}$ grade students who attended high schools in East Godavari County, Andhra Pradesh. He was runner-up in state level science seminar on the issues related to world pollution and global warming, and got many awards for extra curricular activities such as creative writing and science quiz competitions. He ranked 1$^{st}$ in his high school senior class and was selected for both National and State Merit Scholarships for his academic excellence. He graduated from Jawaharlal Nehru technological University, Kakinada, with a Bachelor of Technology in Mechanical Engineering degree in July 1999. He had the highest grade in his graduation class in the Department of Mechanical Engineering. Upon graduation, he joined Clemson University in Fall 1999. There, he received his Master of Science in Industrial Engineering degree with human factors engineering as specialization in May 2001. With a strong desire of continuing research in human computer interaction area, he joined the doctoral program at Wright State University in December 2001. He transferred to LSU when his major professor Dr. Craig Harvey moved to Louisiana State University in Fall 2002. He worked as a research and teaching assistant in Computer, Human, and Machine Performance Laboratory and Human Factors Laboratory in the Department of Industrial Engineering at Louisiana State University from Fall 2002 to Fall 2005. He plans to start his postdoctoral work at Ball State University from February 2006, and is scheduled to graduate in May 2006.